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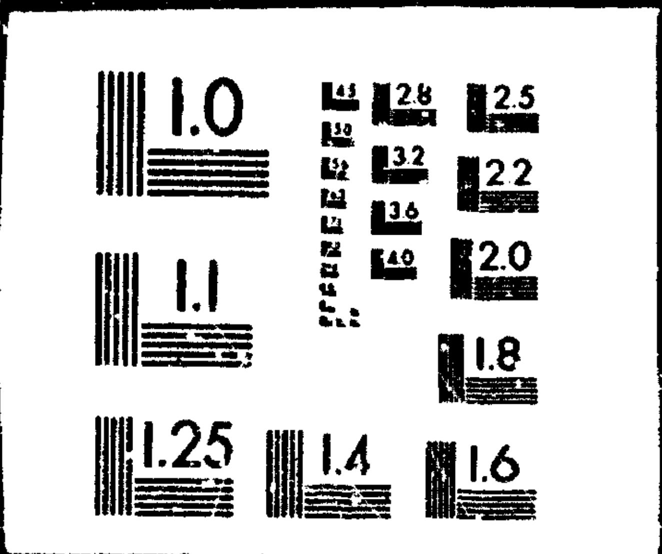

PB81-196537

# Safety Effectiveness Evaluation
# The Improvement of Nighttime Conspicuity of Railroad Trains

(U.S.) National Transportation Safety Board
Washington, DC

Prepared for

National Transportation Safety Board
Washington, DC

3 Apr 81

U.S. Department of Commerce
National Technical Information Service
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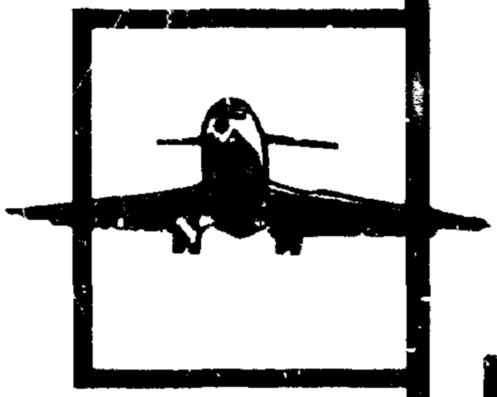
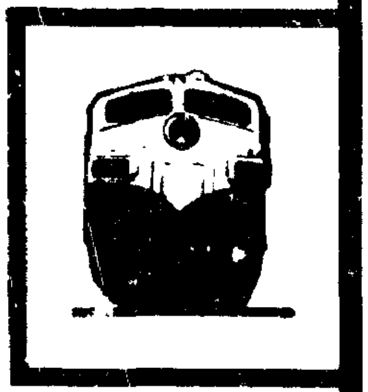


# NATIONAL TRANSPORTATION SAFETY BOARD



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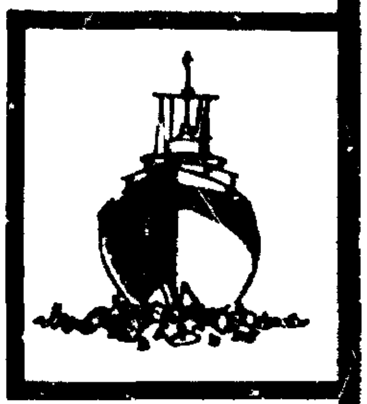
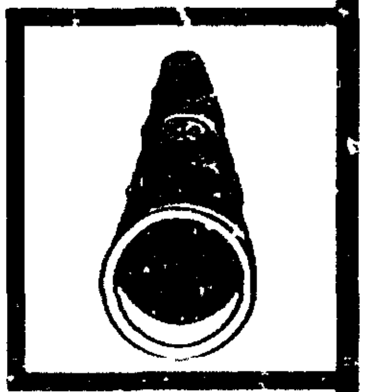


# SAFETY EFFECTIVENESS EVALUATION-- THE IMPROVEMENT OF NIGHTTIME CONSPICUITY OF RAILROAD TRAINS



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16. Abstract


The National Transportation Safety Board examined nighttime accidents in which highway vehicles strike trains that block grade crossings. There is adequate evidence to suggest that this type of accident is strongly influenced by motorists' inability to perceive the presence of trains in crossings because trains lack conspicuity within their environment. This type of accident results each year in approximately 1,800 collisions with 140 persons killed and 800 injured. The Safety Board reviewed pertinent research undertaken by the Federal Railroad Administration (FRA) on a known countermeasure--reflectorization.

The Safety Board issued recommendations to the FRA to develop and issue an advance notice of proposed rulemaking within 6 months for the improvement of nighttime train car and locomotive visibility at grade crossings to aid in preventing accidents in which motor vehicles run into the sides of trains at night. Additionally, the Board recommended that the FRA cooperate with the Federal Highway Administration, the National Committee on Uniform Traffic Control Devices, and the Association of American Railroads to plan and institute a research program on criteria for the use of reflectorization devices and materials.


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## CONTENTS

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

SAFETY EFFECTIVENESS EVALUATION

Adopted: April 3, 1981

# THE IMPROVEMENT OF NIGHTTIME CONSPICUITY OF RAILROAD TRAINS

## INTRODUCTION

The most prevalent type of railroad accident is a collision between a train and a motor vehicle at a railroad-highway grade crossing. This type of accident annually accounts for about 900 fatalities, 12,000 accidents, 4,000 injuries and property damage in excess of $300 million. Railroad-highway grade crossing accidents involve both collisions where the train strikes a motor vehicle and where a motor vehicle strikes the side of a train. This report is concerned only with the nighttime aspect of the latter problem, namely motor vehicles striking trains in darkness.

Accidents in which a motorist strikes a train that is occupying a grade crossing during hours of darkness have involved about 1,800 collisions each year resulting in 140 persons killed and 800 injured. (See figure 1.) There is adequate evidence to suggest that this type of accident is strongly influenced by motorists' inability to perceive the presence of trains in crossings because trains lack conspicuity 1/within their environment; the sides of trains are normally dark in color, unlighted, and without light-reflecting devices. 2/ However, the problem is known and countermeasures are available.

Grade crossing separation, the ideal solution to eliminating grade crossing accidents, is costly. The average cost is about $1.5 million per separation, and only a limited number of these improvements are made each year, according to a recent General Accounting Office (GAO) audit. The audit found that funding by the Federal Highway Administration (FHWA) to the States for grade separation totaled only $17.5 million for the years 1975 to 1977. Additionally, only 11 of the 50 States had undertaken major separation projects of $50,000 or more. The cost to close or separate all crossings nationwide would be in the billions of dollars. Grade separation on a large scale, therefore, is neither economically feasible nor reasonable as a major element in reducing grade crossing accidents.

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1/ In this evaluation, "conspicuity" and "visibility" are used interchangeably to describe the characteristic of an object that makes it readily seen and perceived by a motorist.

2/ Various materials including plastic tape, sheeting, special paint, and plastic lenses which are designed to reflect light are considered as "reflecting devices." Examples of reflectorized material use include reflectorized license plates, highway signs and markings, and disabled motor vehicle warning devices.

Figure 1.--In November 1979, an automobile struck the side of this train in a nighttime accident at Salida, California, and derailed 31 loaded freight cars, 1 of which was carrying chlorine. Fortunately, the chlorine did not escape. The automobile driver was killed and the three passengers were injured. Over $1 million in property damage was sustained in this accident.

Federal efforts to reduce grade crossing accidents during the 1970's focused on the development and installation of active or passive warning systems to clert highway users to the accident hazard at grade crossings. Active warning systems use devices such as gates and flashing lights, and passive warning systems use devices such as posted advance warning signs, pavement markings, and roadside crossbucks. (See appendixes A and B.) Typically, the average cost of signal light installations is about $32,000, and gates with lights cost about $52,000. From fiscal year 1974 to fiscal year 1979, the Federal funds obligated from railroad crossing improvement grants for such protection devices provided for only 10,000 improvement projects. About 22 percent of the 217,000 public crossings in the United States are equipped with automatic, active devices; 70 percent are equipped with passive devices; and 7 percent are unmarked. Thus, at about three-fourths of the crossings, if the motorist fails to see the advance warning signals or the crossbucks, if any, there is no fail-safe system to provide timely warning of the actual presence of a train on the crossing or the approach of one if the train itself is not readily apparent. Federal Railroad Administration (FRA) accident data show that 46 percent of crossing accidents occur at locations with active signals. 3/

In 1976, the U. S. Department of Transportation (DOT) published the National Highway Safety Needs Report which estimated the cost and future effectiveness of numerous safety countermeasures, either proposed or currently underway. The programs were ranked in several ways, including fatality reduction for "Railroad-Highway Grade Crossing Protection, excluding automatic gates." When ranked by decreasing cost effectiveness for total fatalities over a 10-year period, it ranked 35 among 37 countermeasures for the highway program. The projected cost for this program (in 1976 dollars) was $974 million and the projected benefit was 276 lives saved.

The Federal-Aid Highway Acts of 1973 and 1976 and the Highway Safety Act of 1978 authorize $1.35 billion for rail-highway safety through fiscal year 1982. Funds for such improvement, however, are authorized only for public highway grade crossing safety. This excludes the 141,000 private grade crossings, over a third of all the grade crossings.

As early as 1938, researchers noted that it was twice as likely that an automobile would strike a train at night as in the daytime. In 1941, researchers found that only 4 percent of grade crossing accidents in which an automobile struck a train occurred during daylight. At night, 36 percent of these grade crossing accidents happened in this manner. 4/ In 1952, another study showed that the risk of a motor vehicle running into the side of a train was eight to nine times greater at night than in daylight. The study concluded that the drivers did not see the trains in time to prevent the accidents. 5/

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3/ Federal Railroad Administration, Railroad Highway Grade Crossing Accident Statistics, 1979.

4/ A.R. Lauer and E. H. Silver, "Survey of Research on Night Driving in Relation to Vision," Optometric Weekly, March 1941.

5/ H. J. Stadler and A. R. Lauer, "Effective Use of Reflectorized Materials on Railroad Boxcars," Highway Research Board Bulletin, No. 89, 1954.

FRA statistics for 1978 for accidents involving motor vehicles running into trains at dawn, dusk, and night indicated that there are six times as many vehicles hitting standing trains at night as in the daytime. The statistics showed that no persons were killed in daytime accidents of this type while 18 were killed at night. There were 8.5 times as many persons injured and killed in such lower visibility accidents than in daytime accidents.

Conditions such as fog, rain, snow, haze, and even smoke can diminish a driver's ability to see and perceive a train. Such reduced visibility conditions are not uncommon. In 1979, there were 1,832 accidents in which a motor vehicle struck a train during nighttime conditions. Of the 1,832 accidents, 1,458 (79.6 percent) occurred in clear or cloudy conditions while only 181 (9.9 percent) occurred in rain, 100 (5.5 percent) in fog, 84 (4.6 percent) in snow, and 9 (0.4 percent) in sleet.

Of the 1,832 accidents, only 659 were reported to be at crossings with some form of illumination. Statistics also show that 44.4 percent of the persons injured and killed were involved in accidents where the train was either stopped or traveling under 10 mph.

The FRA has been aware of the problem of motor vehicles striking trains at night for many years. It has studied the overall grade crossing accident problem repeatedly and developed research results that suggest that reflectorizing the sides of train cars would be beneficial. In spite of the positive results of its own research, however, the FRA has not targeted the problem of the nighttime accident in which a motor vehicle strikes a train for a specific countermeasure program. In 1978, the GAO criticized the DOT for not providing sufficient guidance to warn or protect motorists where railroads cut across public highways. 6/

It is apparent that nighttime accidents at grade crossings where a motorist strikes a train could be decreased by improving the motorist's perception of a train crossing the highway. Specific attention in this report is given to a method of improving train conspicuity at all railroad-highway crossings: reflectorization of the railroad rolling stock. Legislation to require train car reflectorization has been considered periodically by the Congress, but it has not been passed, largely because of the alleged high cost of reflectorization, questions about the effectiveness of reflectorized materials on railroad cars, and possible installation and maintenance problems.

## REFLECTORIZATION

The safety benefits of transportation vehicle reflectorization have been recognized for many years in the United States. The use of reflective materials to enhance motorist awareness of potential hazards has gradually gained in acceptance as its effectiveness in reducing accidents has been substantiated. A pioneer study to measure the benefit of reflective markings on highway vehicles,

6/ General Accounting Office Report No CED. 78-83, "Railroad Crossing Safety--At What Price?" April 25, 1978.

performed by a bus company in the late 1940's, revealed a reduction in accidents in which a bus was struck by another vehicle. 7/ A 1957 study made after the U.S. Post Office Department changed the colors of its vehicle fleet from olive drab to red, white, and blue (the red was reflectorized tape) concluded that "the difference between the two groups was most pronounced for accidents where other vehicles rear-ended the postal vehicles (50 such accidents for the olive drab group, and 24 for the red, white, and blue group)." 8/

Since 1971, in England, heavy goods vehicles (those over 3 tons unladen) have been required to display distinctive rear markings of reflective material to improve nighttime conspicuity. A 1976 evaluation of the effects of the British regulation found that nighttime rear-end accidents on nonilluminated rural roads involving parked, heavy goods vehicles had a statistically significant reduction. 9/

The U.S. DOT's National Highway Traffic Safety Administration (NHTSA) is seeking ways to make commercial heavy-duty trucks and trailers more conspicuous. The agency has reviewed 400,000 accidents that occurred from 1967 to 1975 and concluded that the major cause of those accidents was the inability of the driver of the striking vehicle to see the truck. There were 20,000 fatalities, 250,000 injuries, and an estimated $1 billion in property damage in those accidents. Analysis of the NHTSA's Fatal Accident Reporting System (FARS) data for 1977 revealed that most rear-end and side collisions of automobiles with tractor-semitrailers occur at night. One theory is that the automobile drivers do not see the semitrailers soon enough to avoid striking them and that making the semitrailers more visible at night should prevent some car-into-trailer collisions. 10/ In an attempt to solve the problem, the NHTSA is evaluating possible changes in the number and types of lamps as well as the use of reflective markings on trucks and trailers.

A 1979 review of literature on nighttime conspicuity and the effect of reflectorization stated that reflectorization is "theoretically an effective means of increasing the nighttime conspicuity of vehicles, and available empirical data generally support that concept." The review also noted that reflectorization as an aid for increasing conspicuity and safety has been applied to a wide range of vehicles, including trucks, buses, motorcycles, bicycles, and railroad boxcars. 11/

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7/ A. Z. Proulx, 3M Corporation Internal Publication, 1959.
8/ Paul Green, et. al., "Accidents and the Nighttime Conspicuity of Trucks," Highway Safety Research Institute [HSRI], UM-HSRI-79-92, January 1980.
9/ Transport and Road Research Laboratory, Crowthorne/England, "The Effects of Rear Markings on Rear Impact Accidents Involving Heavy Goods Vehicles," 1976.
10/ M. S. Kubacki, "Collisions of Cars with Tractor-Semitrailers,' The HSRI Research Review, Volume 10, No. 3, November-December 1979.
11/ Michael Sivak, "A Review of Literature on Nighttime Conspicuity and Effects of Reflectorization," The HSRI Research Review, Volume 10, No. 3, November-December 1979.

The American automotive industry, through the Motor Vehicle Manufacturers Association, has sponsored independent research on car-into-truck accidents at the Highway Safety Research Institute (HSRI) of the University of Michigan. The purpose of the research was to "determine if enhanced truck conspicuity, making vehicles more visible and recognizable, could be expected to reduce car-into-truck accidents which often involve underride." In a December 1980 letter to the Safety Board, the Motor Vehicle Manufacturers Association summarized the research results:

- Most of the fatal collisions occur at nighttime.
- Semitrailer conspicuity is a problem.
- Collisions could be prevented with the use of additional lights or reflective materials.
- Conspicuity at night is enhanced if luminance is increased by reflectors.
- Research drivers could see a parked nonreflectorized semitrailer at 300 to 400 feet under low headlight beams, and at 1,000 feet when reflective material was applied.
- Research drivers paid more attention to the reflectorized trailers than those that were not reflectorized.
- Car-into-truck collisions can be reduced if truck and trailer conspicuity is enhanced.
- Reflective surface, size, color, and configuration need further research.

In 1973, an extensive study of reflectorization was undertaken by the National Bureau of Standards for the FRA. The report, unpublished by the FRA, concluded that reflectorization of railroad rolling stock would be cost beneficial even if the reflectors were only 75 percent effective. The installation cost of reflectors on all existing rail equipment was computed to be $15 million--an annual cost of $3 million for the expected 5-year life of the equipment. The study stated that annual benefits would total $6 million in reduced loss of life, injuries, and property damage. 12/

12/ J. Richard Lepkowski and William F. Mullis, "Consideration for Improving the Conspicuity of Railroad Rolling Stock," Phase V Report FRA-AR 20033, prepared by the National Bureau of Standards, September 1973.

Another study, completed in 1975 by the DOT Transportation Systems Center, developed guidelines for improving the conspicuity of trains at grade crossings. The study suggested an estimated benefit of $10 million per year at an estimated annual cost of $500,000 per year. These figures indicated a benefit/cost ratio of 20. The study indicated that use of reflective paint for required labeling and other markings appears to be an efficient technique to improve the visibility of railroad freight equipment. The study suggested that a reflectorization program could be expected to yield substantial benefits. 13/

The most recent research, 14/ completed in 1979 by the FRA but unpublished, concluded that a reflectorization program would show an expected benefit/cost ratio of 1.6 to 3.5, depending on whether the low or high cost estimate is used. The maximum annual benefits possible from reflectorization, the study concluded, would be the avoidance of 817 accidents, 48 fatalities, and 329 injuries annually. The report explored reflector effectiveness in great detail. It showed that sides of railroad cars would be visible at distances up to 1,000 feet if illuminated by low-beam lights, and up to 2,000 feet if illuminated by high-beam lights. It concluded that these distances would allow for the safe stopping of the motoring public under most conditions experienced at grade crossings. The maximum stopping distance required for most vehicles and highway driving speeds was computed to be 500 feet.

The FRA report also estimated that the cost of a reflectorization program for the entire railroad fleet in 1977 dollars would annually range from $2.7 to $5.8 million over a 10-year period. This cost included initial materials and installation, annual replacement of reflectors destroyed by vandals or train operation, maintenance, cleaning, and program implementation. The report also estimates that 27 deaths per year would be prevented at crossings with passive protection and 21 at crossings with active protection. The expenditure of up to $5.8 million, therefore, would equate to 480 lives saved over a 10-year period.

The FRA report also computed nighttime visibility distances for nonreflectorized railroad cars of the common railroad colors--black, red, and white. It concluded that a motorist who approached grade crossings with low-beam headlights would not see the rail equipment in time to make a safe stop at speeds as low as 20 mph. The report concluded that visibility ranges of nonreflectorized railroad cars were significantly shorter than the visibility ranges of those that are reflectorized.

Another study performed for the FRA, which cited work completed by the Canadian National Railway, showed that dirt and grime can build up on the reflectorized material and that the reflectors will have to be cleaned at least once

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13/ John B. Hopkins and A. T. Newfell, "Guidelines for Enhancement of Visual Conspicuity of Trains at Grade Crossings," Report No. ORD 75-71, Transportation Systems Center, May 1975.

14/ Richard G. McGinnis, "The Benefits and Costs of a Program to Reflectorize the U.S. Fleet of Railroad Rolling Stock," Report No. FRA-OPPD-79-12, Bucknell University, January 1979.

every 1 or 2 years. 15/ However, the study was based on the use of Automatic Car Identification (ACI) labels on railroad cars using engineering-grade reflective material. The ACI labels, small areas of reflectorized material with complex patterns, were part of a national automated program to identify freight equipment. Using reflective material for safety purposes would probably require larger area applications and dirt and grime accumulations are not likely to be so critical. In addition, a high-intensity reflector material has been developed which requires less frequent cleaning maintenance.

Another recent research summary, 16/ which addressed truck markings and conspicuity, indicated that long-term aging and loss of original brightness due to dirt accumulation would be 33 percent. In this research, the effectiveness of brightness levels of 1/3 and 1/9 brightness was compared with that of the original material. Although some loss of performance was noted, even at 1/9 original brightness, detection and shape recognition could be made from about 1,500 feet away.

The state-of-the-art of reflective materials has improved substantially over the past 10 years. The quality and effectiveness of the reflective paints, tapes, sheeting, and hard (plastic) reflectors (see figures 2 to 7), coupled with relative low cost, easy application, long-term wear, and reliability, have made these devices cost-effective for safety applications.

Reflectorization has been mandated by the Consumer Product Safety Commission on bicycles and by the DOT on motor vehicles and as warning devices for certain disabled or stopped vehicles. The FHWA's Manual on Uniform Traffic Control Devices (MUTCD) also requires that all highway regulatory and warning signs, road delineators, and pavement markings, as well as railroad crossing signs, pavement markings, and gates, be reflectorized. (See appendix B.)

The 1979 McGinnis study for the FRA indicated that while the effectiveness of reflectors are reduced by visibility conditions, they are invariably more visible than nonreflectorized objects. The study reported that "reductions in reflector illuminance caused by light haze conditions (corresponds to a 5-mile daytime visibility condition) are thus 6.6 percent, 8.7 percent, 10.7 percent, and 12.7 percent for vehicle-reflector separations of 300 ft (91 m), 400 ft (122 m), 500 ft (152 m) and 600 ft (183 m) respectively." Additionally, the research indicated that of all grade crossing accidents reviewed in the study, only 7.3 percent had an adverse weather factor that would have significantly affected reflector effectiveness. In calculating the benefits of reflectors, the researcher did not include accidents affected by adverse weather.

15/ Hector C. Ingrao, "Optical Automatic Car Identification (OACI): Optical Properties of Labels," Federal Railroad Administration, June 1977.
16/ R.C. Vanstrum and R.L. Austin, "Truck Markings and Conspicuity: A Report on Two Demonstrations," 3M Company, September 1979.

Actions to improve the conspicuity of trains have been undertaken voluntarily by a number of railroads, including but not limited to Amtrak, the Atchinson, Topeka and Santa Fe (Santa Fe); the Burlington Northern; the SOO Line; the St. Lawrence Railway; and the Canadian railroad systems. Amtrak indicated to the Safety Board staff that the reflective tape applied to its passenger trains is for safety purposes, particularly to make its equipment visible at night. The Santa Fe has applied reflective panels (6 inch by 6 inch every 8 feet) on new and rebuilt equipment. The number of Santa Fe units with reflective material was estimated at 20,000. The SOO Line has applied reflective material to its equipment for advertisement purposes, improvement of nighttime yard operations, and for safety. Although none of the railroads had completed any formal evaluation of reflective materials, two of the railroads (Amtrak and SOO Line) indicated complete satisfaction with their reflectorization programs. The SOO Line official stated that some reflective material applied in the mid-1960's was still performing adequately and that SOO Line had no maintenance problems with its reflective materials. Amtrak indicated similar experience.

Some railroads are opposed to train car reflectorization. One railroad has cited a 1963 study that indicated no benefits would be derived from reflectorization. 17/ In April 1965, the National Association of Railroad and Utility Commissioners opposed a bill proposed by Congress for train car reflectorization. On the other hand, officials from two railroads who have examined research on reflectors did not reject the potential safety benefits. Indeed, one reviewer has stated: "The reflectorization of railroad rolling stock appears to me to be a good idea." 18/

The Association of American Railroads (AAR) did not have a documented position or any research on this safety issue. However, an AAR safety official has informally said that he does not believe that, in general, the benefits of reflectorization justify the cost.

The FRA already has recognized the need to improve the conspicuity of the trailing end of the rear car of all passenger, commuter, and freight trains. In 49 CFR 221, "Rear End Marking Device," the FRA prescribes minimum requirements for highly visible marking devices for the rear car. The purpose of this rule, promulgated in January 1977, is to improve the visibility of the train, to prevent rear-end collisions and, thereby, to protect railroad employees and passengers from the severe consequences of these collisions. In the rulemaking proposal (Federal Register, Volume 41, No. 223, November 17, 1976), the FRA stated that, "the highly visible markers will provide an additional or back-up safety feature by which to determine the presence of a train ahead on the same track and to distinguish it from other objects generally found in the visual field along the right-of-way so as to provide an additional opportunity to take appropriate action to avoid a collision."

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17/ Mr. James B. McCloskey, Assistant Solicitor General, Norfolk and Western Railway Company to Mr. Jack Green, National Safety Council, dated March 13, 1980.

18/ Louis T. Cerny, Erie Western Railway Company review of "Reflectorization of Railroad Rolling Stock," January 1979.


Figure 2.--Daytime photograph of reflectorized train car at a grade crossing.

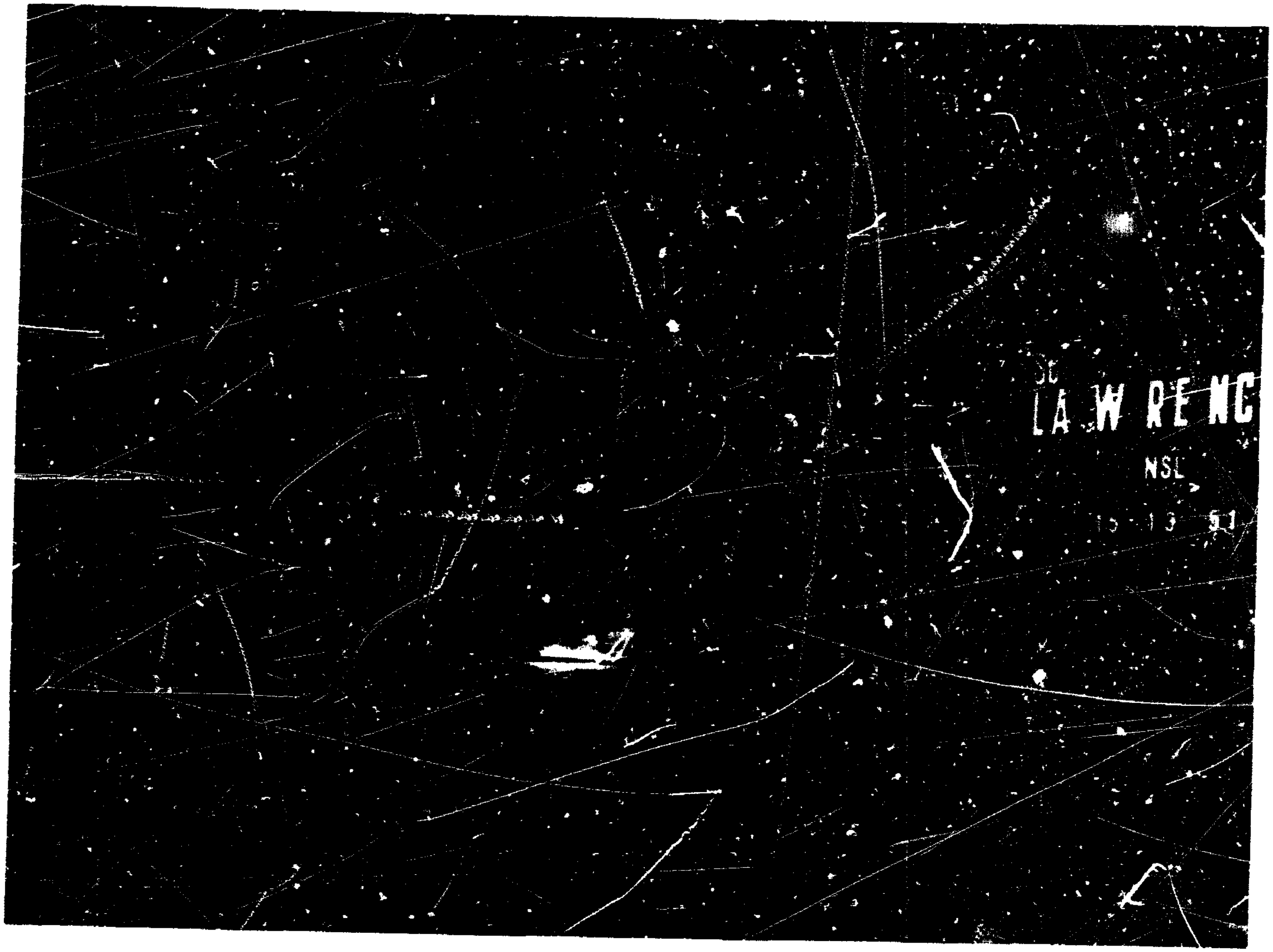


Figure 3.--Nighttime photograph of reflectorized train car shown in figure 2.

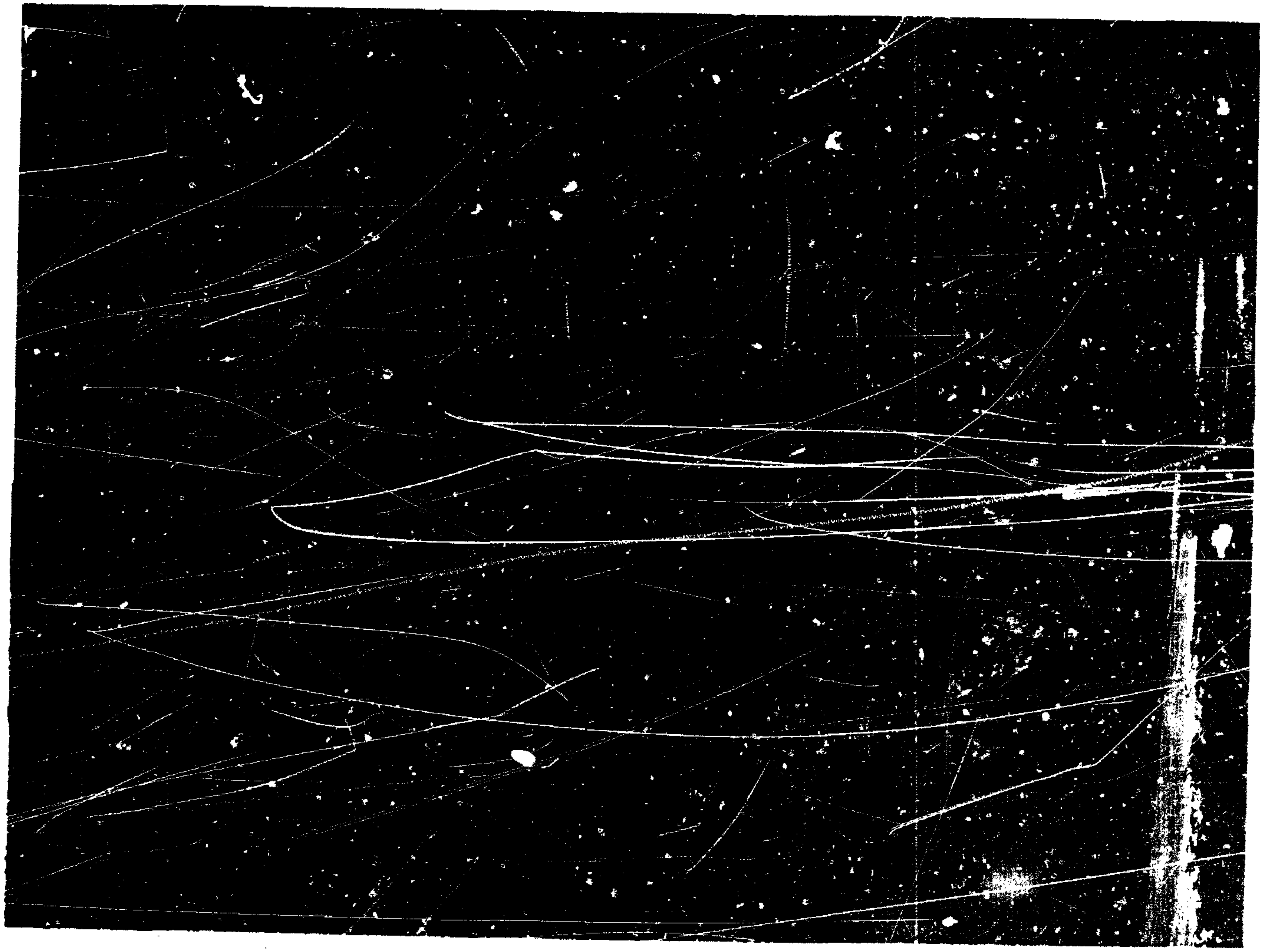

Figure 4.--Daytime photograph of reflectorized train cars in a train switching yard.

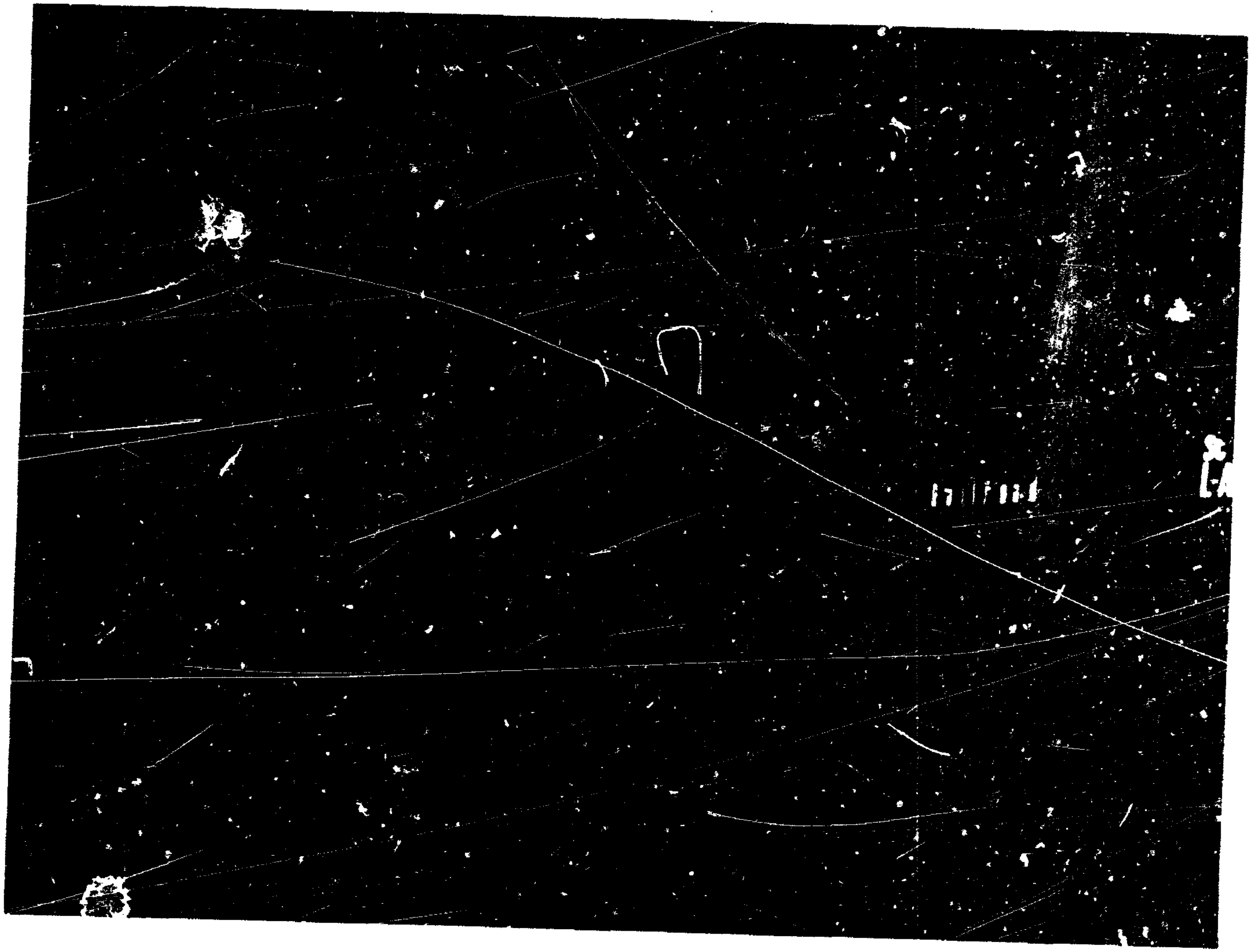

Figure 5.--Nighttime photograph of train cars in figure 4 snows the effectiveness of reflectorized materials at both right and oblique angles.

Figure 6.--Daytime photograph of mostly nonreflectorized (left) and reflectorized (right) train cars.

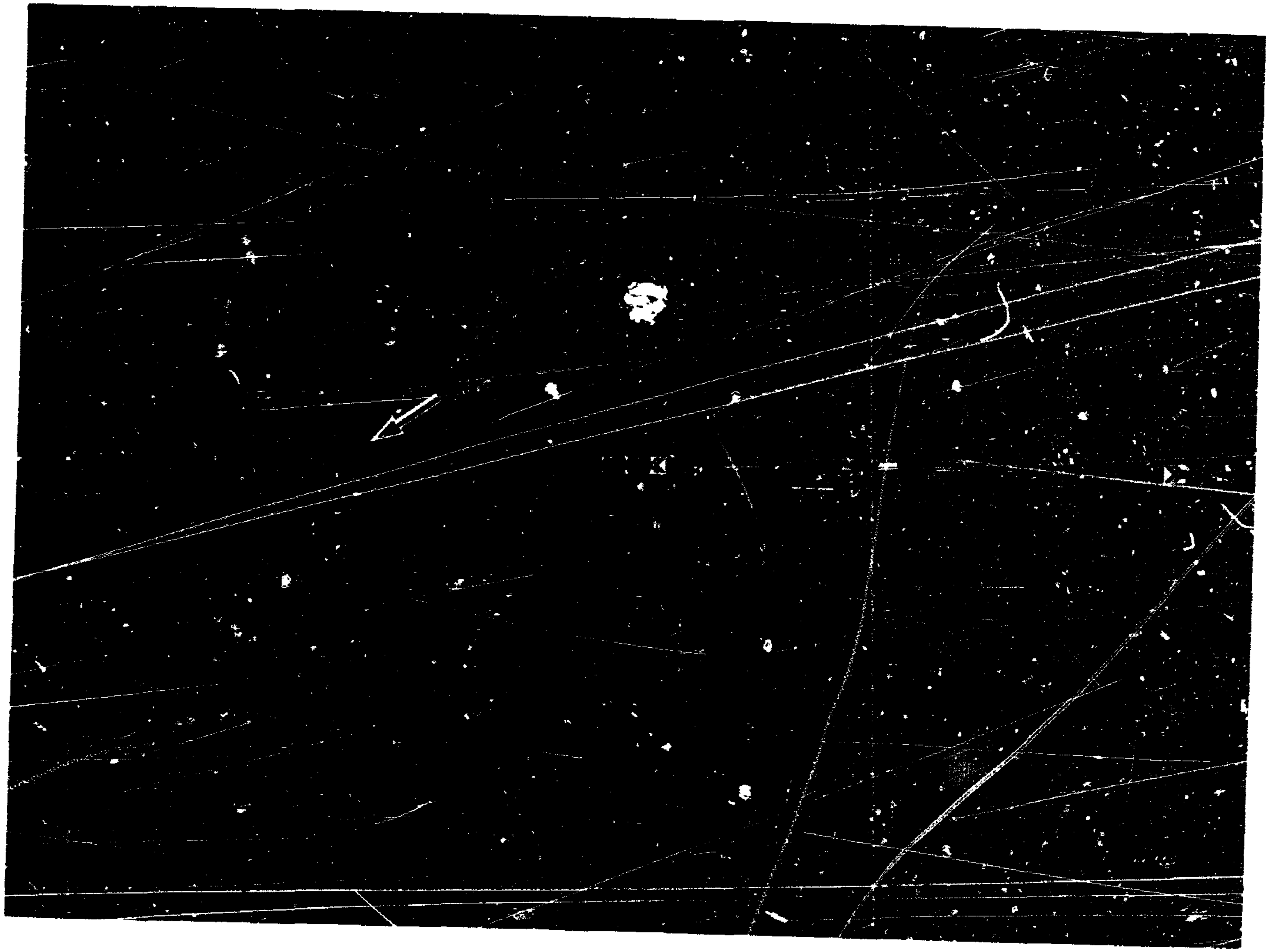

Figure 7.--Nighttime photograph of train cars in figure 6. Only the reflectorized word "AMTRAK" is visible on the left car. (See arrow).

Other government bodies in the United States and Canada have recognized the value of reflectorizing train cars. The Georgia State House of Representatives expressed its concern in a January 16, 1979, resolution on train-motor vehicle accidents. In part, it recommended various means, including reflectorizing train cars, "to insure that all railcars and locomotives are clearly visible during night hours at railroad grade crossings." The resolution was directed to various members of Congress and several Federal agencies, including the DOT, the Interstate Commerce Commission (ICC), and the Safety Board.

A Wisconsin State law, enacted in 1971, requires all train cars built or repaired in the State to be reflectorized. Before that, the SOO Line building and maintenance operation in Fond du Lac, Wisconsin, was applying reflectorization and currently reflectorizes about 150 new cars and 700 reworked cars per year. Because SOO Line cars and nonreflectorized equipment from other train companies are combined to form trains that are seldom, if ever, 100-percent reflectorized, neither the SOO Line nor the State of Wisconsin has evaluated the effectiveness of reflectorized train cars. The SOO Line is the only train car builder operating in Wisconsin.

In 1959, the Board of Transport Commissioners for Canada started a grade crossing safety program to place reflective markings on the sides of Canadian railroad cars. The reflectorization program was initiated at the Provinces' insistence because of the many unmarked grade crossings. The program provided for government funding of 80 percent of the cost. The Canadian program has reflectorized approximately 121,000 freight cars at a cost of $500,000. A mitigating factor, however, is the fact that approximately one-half of the train cars on Canadian tracks are from the United States. Because reflectorization is not required in the United States, the potential effectiveness of the Canadian grade crossing safety program is lessened. Moving or standing trains with large numbers of nonreflectorized cars will not provide the continuity of conspicuity needed to indicate to the motorist the presence of a train in the crossing.

In addition to the above governmental activities, the International Association of Chiefs of Police adopted a resolution at its 1980 annual meeting encouraging the nation's railroads "to affix either lighting equipment or reflective materials on the sides of all railroad cars . . . ." This endorsement for increased train conspicuity is significant because police officers are the first on scene to investigate these accidents, and this official position reflects an informed recommendation to help prevent nighttime accidents in which a motor vehicle strikes a train.

## ACCIDENT INVESTIGATIONS

The following descriptions of accidents involving motor vehicles striking trains at night which the Safety Board has investigated illustrate conditions that can be encountered:

Cowdrey, Colorado

On September 5, 1979, at about 5:45 a.m., an empty Union Pacific coal train was moving westbound across Colorado State Highway 127 north of Walden, Colorado, at a speed of 12 mph. About 22 seconds after the train locomotive passed through the grade crossing, a loaded southbound tractor-semitrailer struck one of the trailing coal cars. Skidmarks on the paving surface were 179 feet long, indicating the driver responded to the train presence just seconds before impact. The cab of the truck was crushed in the impact and six cars of the train derailed. The truckdriver was thrown from the truck and killed.

The presence of the crossing was indicated by a standard warning sign 560 feet before the crossing, pavement markings 400 feet in advance of the crossing (see figure 8), and crossbucks at the crossing. There was no active warning device or permanent illumination.

The accident occurred in twilight. The weather was clear and the road was dry. The ambient light did not aid significantly in the observation of features beyond the range of vehicle headlights. The train's coal cars were a dark red color. The locomotive was equipped with a flashing yellow light and was 400 feet beyond the crossing at the time of the impact.

Visibility tests, conducted at the approximate time of day the accident occurred and using an automobile with headlights on low beam, indicated that the dark-colored railroad cars on the crossing would not have been readily visible to southbound traffic until about 230 feet from the crossing.

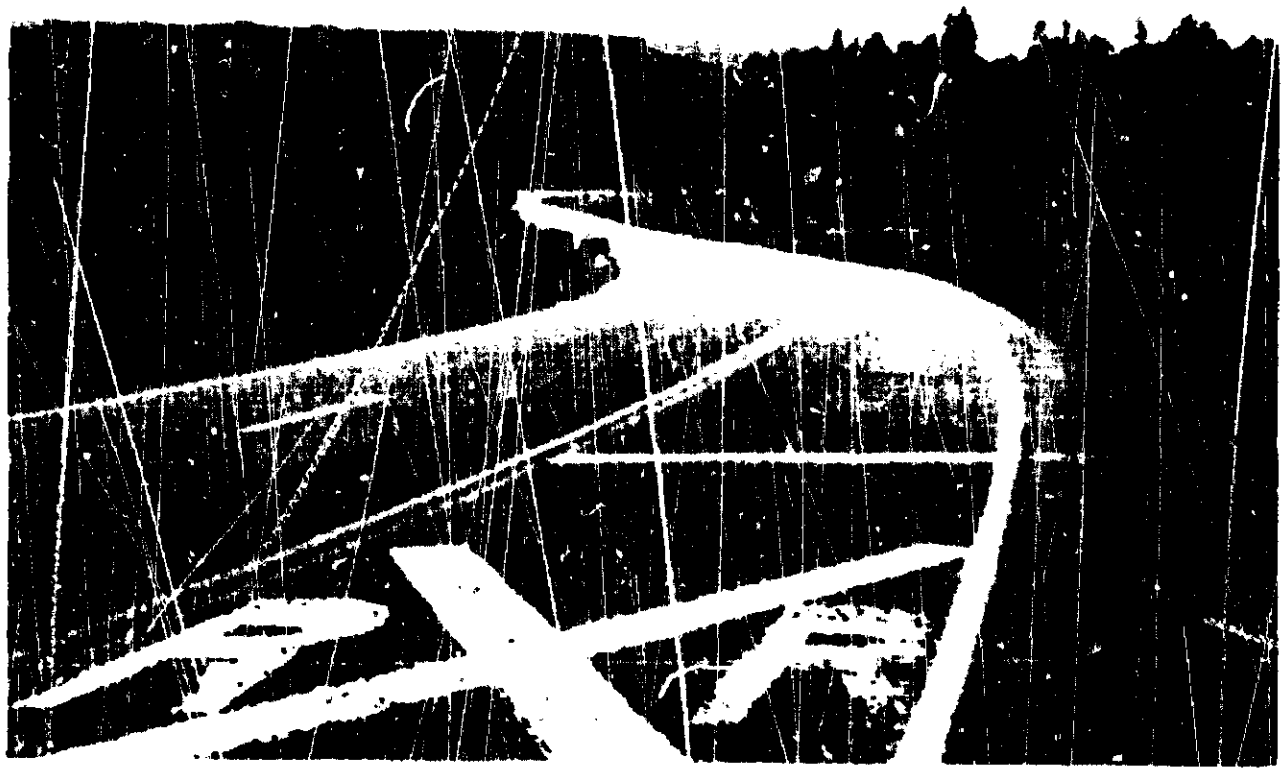

Figure 8--View of the Cowdrey, Colorado, grade crossing some 400 feet from the point where a tractor-semitrailer struck a coal train at twilight.

The truckdriver was a 63-year old resident of Greeley, Colorado, with about 30 years of driving experience, most of which involved operations as an independent driver for hire. He was certified as medically qualified to drive in interstate commerce. His driver log was current and reflected compliance with the Federal regulations regarding hours of service. The truckdriver had started his shift about 3 a.m. at Greeley. He had been on duty 2 hours 45 minutes when the accident occurred.

The facts of this accident suggest that if the truckdriver had been aware of the presence of the train across the highway at a distance of 500 or more feet, he could have stopped safely and this accident could have been prevented.

The Colorado Public Utilities Commission (PUC) had inspected the crossing in July 1979 and determined that there was no need for automatic protection at the crossing. After this accident, the Colorado PUC determined that the crossing justified additional protection and planned to install active warning lights at the crossing and advance yellow blinking warning lights activated by the crossing lights.

Pratville, Alabama

On January 17, 1980, about 12:14 a.m., a 19-year-old college student was injured when the car she was driving ran into the 42nd car of a 65-car, slow-moving freight train at a grade crossing in Pratville, Alabama. The accident occurred during rainy weather. The grade crossing is normally lighted, but the evening of the accident it was dark because vandals had shot out the overhead utility light. A nonreflectorized crossbuck sign marked the location of the crossing.

The motorist was familiar with the area and lived only 1 1/2 miles from the crossing. The night of the accident, she was approaching the crossing at the posted 35-mph speed limit. Her first indication that a train was on the crossing was the motion of the train cars. She instantly applied the brakes and steered sharply to the left. Her automobile swerved but skidded into the train and struck a train car in the wheel area. The impact forced the automobile away from the train into an adjacent ditch.

The roadway section driven by the student just before the grade crossing was practically level and straight, and the visibility for the motorist was unobstructed by bushes, billboards, the rainy weather, or other objects for 450 feet. This distance would have allowed her to observe a readily visible train and react sufficiently to stop her vehicle in time to prevent the accident, even under the rainy weather conditions. Under wet pavement conditions, according to the American Association of State Highway and Transportation Officials, 263 feet of pavement are required to stop a vehicle traveling at 36 mph.

The train was traveling about 10 mph through the intersection when the accident occurred. Based upon the automobile's estimated 35-mph speed and the fact that it struck the 42nd train car, the lead locomotive unit was approximately 0.5 mile past the intersection. This means that the locomotive passed through the intersection almost 3 minutes before the collision, when the automobile was some 1.7 miles from the grade crossing. This rendered the locomotive's horn and light warning system ineffective for this driver.

The nonreflectorized railroad crossbucks and a highway stop sign were the only traffic devices at the crossing. The investigating police officer reported that the stop sign was not standing perpendicular but was leaning at an angle away from the roadway.

Valentine, Nebraska

Shortly after 1 a.m., on January 27, 1980, an automobile struck the 45th car of a 101-unit freight train stopped on the outskirts of Valentine, Nebraska. The 33-year-old driver crossed the first set of tracks and crashed into the wheel area of a 50-foot-long boxcar that was straddling the roadway. The train was stopped for a crewmember to make a routine walking inspection of train cars. The crossing was marked by nonreflectorized crossbucks.

The driver's view of the crossing was not obstructed by trees, buildings, vehicles, or crops. He lived about 3 blocks from the crossing. Valentine police reported that the driver was apparently not fatigued, asleep, or under the influence of alcohol or drugs. The driver told police that he did not see the train until it was too late to stop. The police chief who responded to the scene told Safety Board investigators that he nearly ran into the train even though he knew it was there and was expecting to stop for it. Further, the chief stated that visibility was clear.

## ANALYSIS

Grade crossing accidents have been reduced in the past 50 years in spite of increasing highway traffic. This has been a result of the joint efforts of the railroad industry, government, private groups, and citizens. The elimination or further substantial reduction of grade crossing accidents will be difficult. The ideal countermeasure--grade separation--is too expensive to be feasible for general implementation. The next preferred solution, the application of active devices such as flashing lights and gates that warn of the approach or possible occupancy of the grade crossing by a train, is not only expensive but also not fully effective. Because of sheer numbers, it is highly unlikely that all crossings, public and private, will ever be equipped with flashing lights or gates. Inflation, the increasing difficulty of obtaining funds, and the massive number of locations to be improved suggest that future grade crossing safety can be enhanced only through more innovative and cost-beneficial countermeasures. Despite FRA statistics that clearly show the failure of active signals to fully protect the public, and despite the lack of adequate analysis of why this is so, the DOT continues to support active signalization as a major safety countermeasure, and fails to address more innovative and cost-beneficial approaches.

The McGinnis reflectorization study performed for the FRA identifies causative relationships in accidents in which a vehicle strikes a train. The study also makes it clear that safety benefits can be derived from a program that improves nighttime train conspicuity for motorists. 19/ This finding is also consistent with current heavy truck research results which indicate the likelihood of accident prevention if those vehicles are made more conspicuous. Initially, the annual savings in lives (48), reduction of injuries (329), and property damage ($807,000) may seem small in terms of either the overall grade crossing losses or the larger highway losses. If, however, the potential savings are compared to the four major categories of fatal railroad accidents in the railroad mode, 20/ the savings are substantial. The projected savings of 48 lives is about 79 percent of the 61 fatalities in "train accidents," or 75 percent of the 64 fatalities in "nontrain incidents" reported by the FRA in 1978.

There is a considerable range in the reflectorization cost estimates largely because of different evaluation methods and references. If the higher cost of $5.8 million per year projected in the FRA's 1979 report is used and distributed to the cost of preventing fatalities, the cost per fatality reduced would be about $121,000. This cost would be a 29 times more effective use of public funds than the program outlined by the DOT in its 1976 study which addresses grade crossing accidents from all causative factors. The DOT proposed to spend $1 billion to save 276 lives in 10 years by installing crossbucks, pavement markings, and active signals, while the expense of reflectorization of railroad cars would be $58 million to save 480 lives in 10 years. These comparisons clearly indicate that reflectorization is a cost-beneficial solution.

In the FRA's 1979 report, grade crossing accidents were divided into four categories, described as follows:

> Category 1 consists of accidents in which the motor vehicle struck the train at a point far enough back along the train to indicate that the driver could have stopped safely if he had detected the train's presence just as it started crossing the highway. To determine which accidents met the criterion, a "critical point" on the train was computed using the motor vehicle speed, the train speed, and the condition of the pavement (dry, wet, or icy). If the motor vehicle hit at or behind the "critical point," the accident was included in category 1 unless the point hit was the first car/unit, in which case the accident was filed under category 2. Accidents involving a motor vehicle hitting a train forward of the "critical point" were included in category 3, while category 4 was comprised of all accidents in which the train hit the motor vehicle.

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19/ Because of the significance of this research and because the FRA has not published it, an article based upon the report, "Reflectorization of the Railroad Rolling Stock," written by the author of the FRA study, is reproduced in appendix C.

20/ FRA fatality statistics for 1978 show that 61 persons were killed in train accidents, 457 in train incidents, 64 in nontrain incidents, and 1,064 at rail-highway crossing accidents.

Relative accident rates for each of the four categories are:

| Item | Category 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Passive warning | | | | |
| Dawn or dusk | 3.7 | 3.1 | 1.4 | 1.7 |
| Night | 9.2 | 4.0 | 0.9 | 1.4 |
| Active warning | | | | |
| Dawn or dusk | 3.2 | 2.6 | 1.5 | 2.1 |
| Night | 7.5 | 3.6 | 1.8 | 2.0 |
| All crossings | | | | |
| Dawn or dusk | 3.4 | 2.[illegible] | 1.4 | 1.9 |
| Night | 8.6 | 3.9 | 1.2 | 1.6 |

According to the report, reflectorization will probably most favorably cause a reduction in category 1 accidents. Category 2 will have a smaller portion that can be eliminated.

The report's analysis also found that "the fact that the nighttime rate of category 1 accidents at actively protected crossings is more than seven times the daytime rate indicates that visibility is a contributing factor in these accidents. Consequently, some accident reduction is expected at actively protected crossings as a result of reflectorization."

The Safety Board believes the FRA study is a major contribution to identifying the problem and offering an effective solution. It is a potential basis for major improvement in one subcategory of grade crossing accidents.

The railroad industry has been slow to accept practices used by other modes of transportation to improve the nighttime conspicuity of vehicles and facilities. Trucks and cars are required by Federal regulations to have lighting and reflectorization on their rear ends and sides in specified colors. Roadways are required to have illumination or reflective markings for indicating hazards, delineating the traveled way, and warning of various conditions. In the marine mode, ships and pleasure craft, many channel markers, and other navigational aids are lighted or reflectorized. Aircraft and aircraft facilities are also lighted to meet night visibility requirements. Railroads, however, are permitted to occupy and temporarily close 217,000 public crossings at any time, day or night, without any requirement that their train equipment be visible to the motorist.

The MUTCD requires that gates used to close the road to motorists at grade crossings be equipped with red and white reflectorized material in addition to the flashing red lights. Reflectorization, by adding greater sighting distances, also adds redundancy to active and passive warning devices already in place. As to the three out of four public crossings that do not have warning lights, much less redundancy, and the 7 percent of public crossings which are not marked by either passive or active devices, reflectorization of railroad cars would serve an essential warning function.

The railroads are divided in their positions regarding the benefits of reflectorization of their equipment. Some railroads have found the markings beneficial while others have questioned the benefits that can be derived from a reflectorization program. The latter suggest that too few lives can be saved for the level of expenditures involved. Those opposed to such improvements suggest it would cost $200 million or more to install reflectors based on a 1964 ICC report. The maintenance of the reflectors also has been cited as a major problem. Some railroads maintain that the level of reflectivity will rapidly degrade due to both dirt and grime as well as rapid aging of the reflective material.

The Safety Board has taken positions in the past regarding the responsibility of owners of trucks to provide protection, at their own expense, to occupants of automobiles in rear-end accidents, regardless of the circumstances that may have resulted in the automobile striking the truck. The Safety Board has recommended in Safety Recommendation H-71-77 that the rear of trucks and truck trailers be designed to prevent a striking automobile from underriding the trailer's rear, causing unnecessary serious injury or death. 21/ The Safety Board believes that railroads have no less an obligation to the motoring public to provide devices that will improve a driver's ability to avoid collisions with the sides of trains through improved train conspicuity. The railroad operating across a public road without an obligation to stop carries with it a responsibility to provide needed protection to the motoring public.

The FRA studies have shown the potential benefits of making trains more conspicuous to the motorist at night. The FRA, the FHWA, and the industry must move rapidly to address the needed improvement for increasing the visibility and presence of a train when it is crossing a public highway. The FRA should first publish an advance notice of proposed rulemaking to gather public and industry comment and information on train reflectorization.

In addition, and in cooperation with the FHWA, the National Committee on Uniform Traffic Control Devices, and the industry, the FRA should develop standard criteria for the type, size, location, colors, and levels of reflectivity to be applied to train locomotives and cars. Such criteria are needed even if the FRA does not mandate their reflectorization. Certain railroads, the State of Wisconsin, and Canada are now using reflective material in some form. Development of standard criteria for reflectorization will benefit voluntary programs as well as ease the burden of any subsequent regulation which may be adopted. Reflectorization has such a favorable potential for reducing accidents that efforts to standardize its use should have high priority.

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21/ "Highway Accident Report--Truck Automobile Underride Collision on Interstate Route I-495 Near Maryland Route 450, New Carrollton, Maryland, June 19, 1970" (NTSB-HAR-71-9).

If the FRA analysis of the responses to the advance notice of proposed rulemaking and of the completed research suggest as positive a safety benefit as the Safety Board believes is likely to be derived from a train reflectorization program, the FRA should take action to implement the program. A program agreed upon by the FRA, the FHWA, and the industry could be either voluntary with full participation or mandatory if all railroads cannot agree to participate. Whether the program is voluntary or mandatory, both minimum standards for the devices and materials used after a prescribed date must be established.

The FRA should consider publishing its more recent research findings in train reflectorization. Its research efforts will not have a beneficial effect if they are not made available to the public and industry.

## CONCLUSIONS

### Findings

1. Annually, approximately 140 persons are killed and 800 injured in 1,800 accidents in which a motor vehicle strikes a train at night.

2. Passive warning devices are used to mark 70 percent of public grade crossings but do not indicate to the motorists the presence of a train blocking the highway.

3. Active devices such as flashing lights used at 22 percent of all public grade crossings have not been fully effective in reducing accidents where the motorist's vehicle runs into the side of a train.

4. In periods of limited visibility at night, dusk, dawn, and during adverse weather conditions, it is difficult for motorists to detect a characteristically dark-colored train in a grade crossing.

5. The nighttime visibility of trains can be improved by using reflective materials on the sides of train cars and locomotives.

6. Improving train conspicuity is different from other countermeasures, since it involves attaching a warning on the rolling stock rather than attempting to improve the warning on the roadway.

7. Greater train nighttime conspicuity not only will improve safety at the 217,000 public crossings, but also at the 141,000 private crossings which are unlikely to be improved through application of active devices because of cost and lack of funding.

8. A grade crossing is the only location on the highway system where a highway can be legally closed without adequate and effective warning to the motorist that such closure has taken place.

9. The FRA has not adopted countermeasures to make trains more visible at nighttime although its own research results, when compared to other approaches suggested by the DOT for reduction of grade crossing accidents, show substantial cost benefits in reducing accidents.

10. Canada has had a government-funded national train car reflectorization program for nearly 20 years. The Canadian grade crossing safety program would benefit if United States train cars were reflectorized.

11. Initiation of rulemaking action is needed to elicit public comment about improving nighttime visibility of trains and the advisibility of reflectorization of the train car fleet, and to collect further information on potential safety effectiveness, costs, evaluation plans, measures of effectiveness, funding sources including grant or tax benefit programs, and technical discussions as to colors, patterns, sizes, configurations, and placement of the reflectorized material.

12. The FRA has not published and distributed current research that provides new information which is needed to help devise new countermeasures for motor vehicle/train accidents at night and points to the cost effectiveness of certain measures such as reflectorization.

13. Further research is needed to establish criteria for using reflective materials on the sides of train cars and locomotives that can be used in voluntary or mandatory programs.

## RECOMMENDATIONS

As a result of this Safety Effectiveness Evaluation, the National Transportation Safety Board recommended that the Federal Railroad Administration:

> Develop and issue an advance notice of proposed rulemaking within 6 months inviting comments on the improvement of nighttime train car and locomotive visibility at grade crossings to aid in preventing accidents in which motor vehicles run into the sides of trains at night. Comments regarding the potential benefits of applying reflective devices or materials to the sides of train cars and locomotives should be particularly solicited. (Class II, Priority Action) (R-81-39)
>
> In cooperation with the Federal Highway Administration, the National Committee on Uniform Traffic Control Devices, and the Association of American Railroads, plan and institute a research program to establish criteria for reflectorization devices and materials for installation on the sides of train cars and locomotives. Such criteria should be designed for use in either voluntary or mandatory programs. Such research should include

size, colors, placement, symbol or message, brightness, expected life, maintenance, and relationship to other reflectorized materials used on trains for commercial purposes. (Class II, Priority Action) (R-81-40)

**BY THE NATIONAL TRANSPORTATION SAFETY BOARD**

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

April 3, 1981

## APPENDIX A

### DEFINITIONS OF WARNING DEVICES

Active warning devices: Warning systems activated by an approaching train; for example, gates, flashing lights, highway signals, wigwags, and bells. The warning system remains activated until the train completely traverses the crossing.

Passive warning devices: Warning systems not automatically activated by an approaching train; these include signs (crossbucks, standard highway signs) and special warning devices. These warning systems generally provide information as to a grade crossing location and do not necessarily inform a motorist of a train's approach or blockage of the roadway.

Railroad advance warnings: Advance warning signs present on any of the highway approaches that indicate the presence of railroad tracks ahead.

Pavement markings: Markings as prescribed or generally similar to those contained in highway traffic manuals, in particular, stoplines and railroad crossing symbols, that indicate the presence of railroad tracks ahead.

# APPENDIX B

## DESCRIPTIONS OF WARNING SYSTEMS FROM THE MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

## Part VIII. TRAFFIC CONTROL SYSTEMS FOR RAILROAD — HIGHWAY GRADE CROSSINGS

### A. GENERAL

**8A-1 Functions**

Traffic control systems for railroad-highway grade crossings include all signs, signals, markings, and illumination devices and their supports along highways approaching and at railroad crossings at grade. The function of these systems is to permit safe and efficient operation of rail and highway traffic over crossings. Traffic control devices shall be consistent with the design and application of the standards contained herein. For the purpose of installation, operation, and maintenance of devices constituting traffic control systems at railroad-highway grade crossings, it is recognized that any crossing of a public road and a railroad is situated on right-of-way available for the use of both highway traffic and railroad traffic on their respective roadways and tracks.

With due regard for safety and for the integrity of operations by highway and railroad users, the highway agency and the railroad company are entitled to jointly occupy the right-of-way in the conduct of their assigned duties. This requires joint responsibility in the traffic control function between the public agency and the railroad. The determination of need and selection of devices at a grade crossing is made by the public agency with jurisdictional authority. Subject to such determination and selection, the design, installation and operation shall be in accordance with the national standards contained herein.

**8A-2 Use of Standard Devices**

The grade crossing traffic control devices, systems, and practices described herein are intended for use both in new installations and at locations where general replacement of present apparatus is made, consistent with Federal and State laws and regulations. To stimulate effective reaction of vehicle operators and pedestrians, these devices, systems, and practices utilize the five basic considerations: design, placement, operation, maintenance, and uniformity employed generally for traffic control devices and described fully in section 1A-2.

**8A-3 Uniform Provisions**

All signs used in grade crossing traffic control systems shall be reflectorized to show the same shape and color to an approaching motorist both by day and by night. Reflectorization may be by one of the methods described in section 2A-18.

Normally, where the distance between tracks, measured along the highway, exceeds 100 feet, additional signs or other appropriate traffic control devices should be used.

No sign or signal shall be located in the center of an undivided roadway except in an island with barrier curbs installed in accordance with the general requirements of Part V with minimum clearance of 2 feet from the face of each curb.

Where it is practical, equipment housing should provide a lateral clearance of 30 feet from the roadway. Adequate clearance should also be provided from tracks in order to reduce the obstruction to motorists sight distance and to reduce the possibility of damage to the housed equipment.

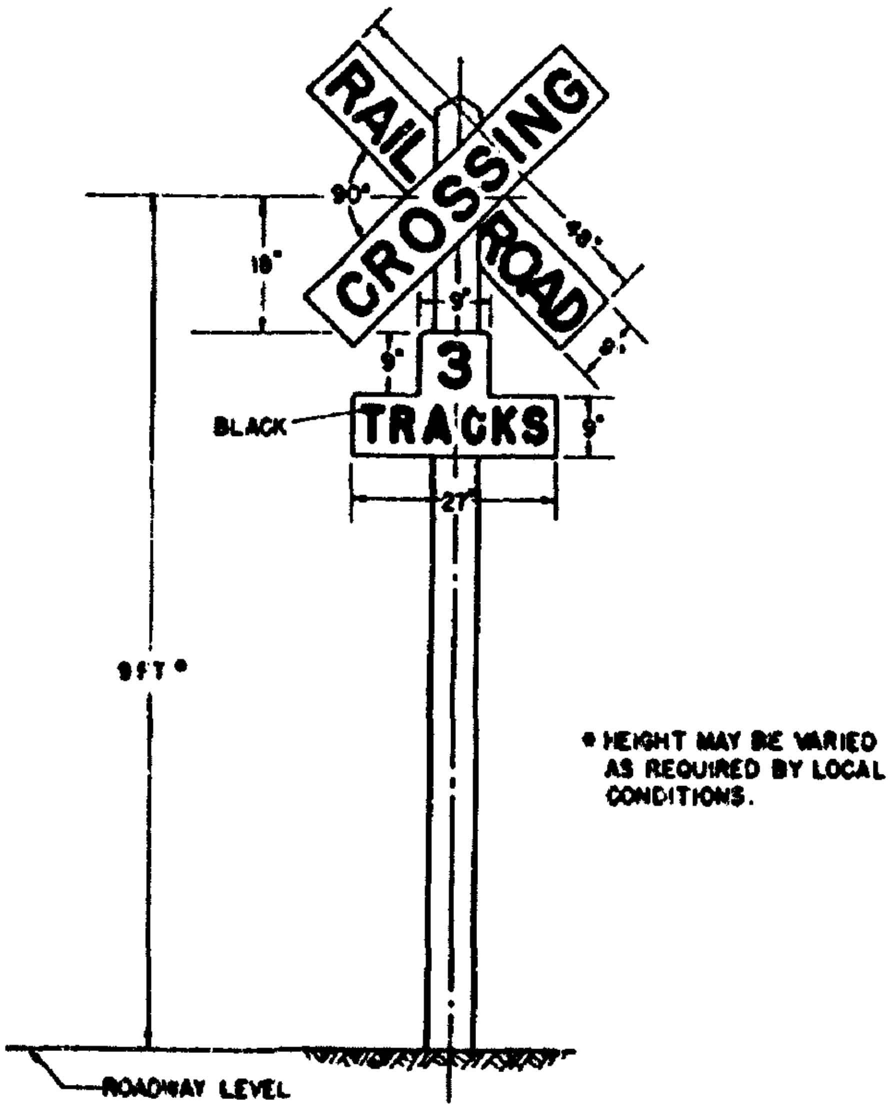
* * *

### 8B-2 Railroad Crossing (Crossbuck) Sign (R15-1, 2)

The railroad crossing sign, commonly identified as the "crossbuck" sign, as a minimum shall be white reflectorized sheeting or equal, with the words RAILROAD CROSSING in black lettering. As a minimum, one crossbuck sign shall be used on each roadway approach to every grade crossing, alone or in combination with other traffic control devices. If there are two or more tracks between the signs, the number of tracks shall be indicated on an auxiliary sign of inverted T shape mounted below the crossbuck in the manner and at the heights indicated in figure 8-1 except that use of this auxiliary sign is optional at crossings with automatic gates.


R15-1
48" x 9"
(drilled for 90-degree mounting)


R15-2
9" x 9"
27" x 9"



### 8B-3 Railroad Advance Warning Sign (W10-1)


W10-1
36" Diameter

A Railroad Advance Warning sign shall be used on each roadway in advance of every grade crossing, except on low volume, low speed roadways crossing minor spurs or other tracks which are infrequently used and which are flagged by train crews, in the business districts of large cities where active grade crossing traffic control devices are in use, or where physical conditions do not permit even a partially effective display of the sign. On divided highways it is desirable to erect an additional sign on the left side of the roadway.

### 8B-4 Pavement Markings

Pavement markings in advance of a grade crossing shall consist of an X, the letters RR, a no passing marking (2-lane roads), and certain transverse lines. Identical markings shall be placed in each approach lane on all paved approaches to grade crossings where grade crossing signals or automatic gates are located, and at all other grade crossings where the prevailing speed of highway traffic is 40 mph or greater.

The markings shall also be placed at crossings where engineering studies indicate there is a significant potential conflict between vehicles and trains. At minor crossings or in urban areas, these markings may be omitted if engineering study indicates that other devices installed provide suitable control.

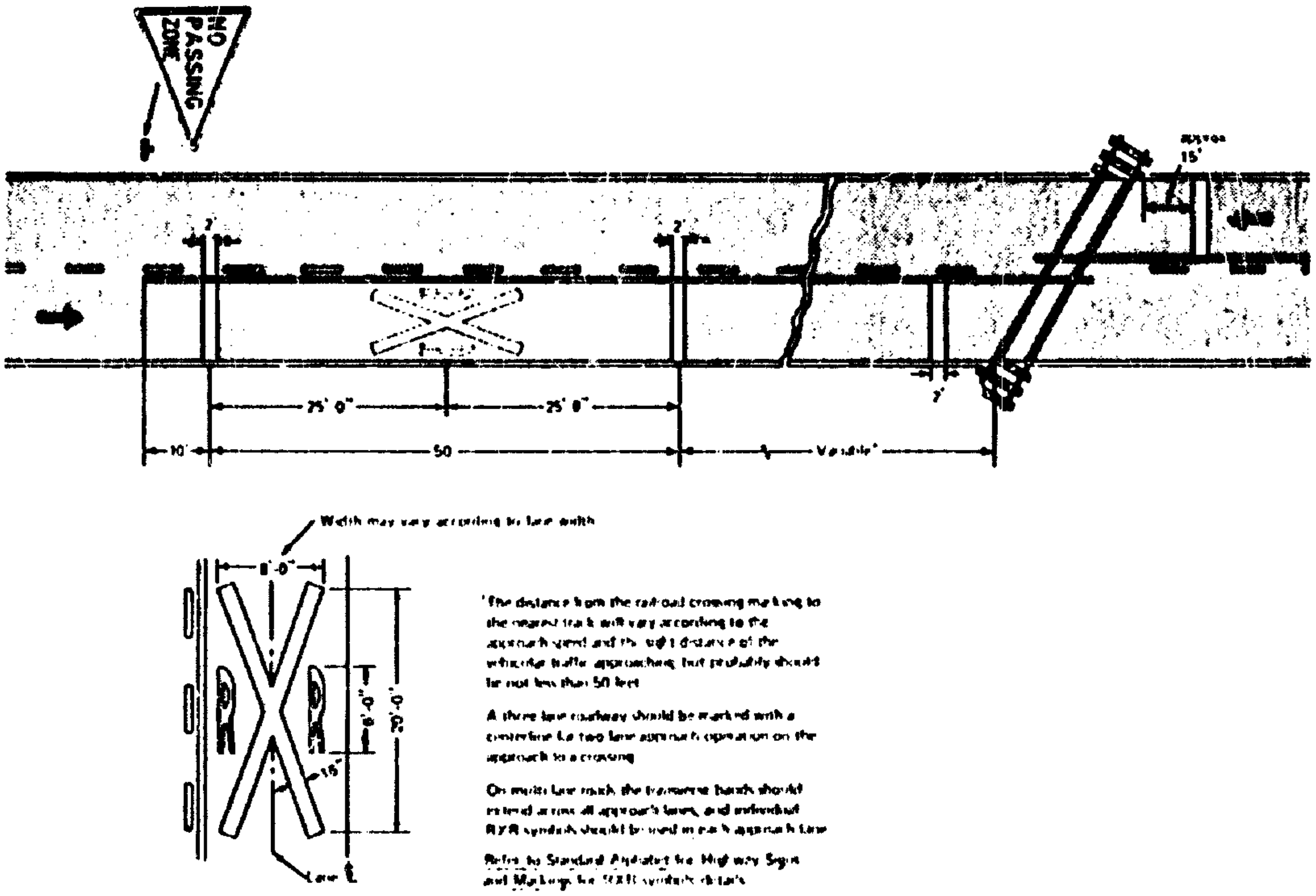



*Figure 8-2. Typical pavement markings at railroad-highway grade crossings.*

* * *

**8C-3 Flashing Light Signal—Cantilever Supported**

Where required for better visibility to approaching traffic, particularly on multi-lane approaches, cantilevered flashing light signals are used in the manner shown in figure 8-4. In addition to the flashing lights cantilevered over the roadways, flashing lights should usually be placed on the supporting post.

Although cantilever signals are more commonly used on multi-lane highways, they are also suitable for other locations where additional emphasis is needed. These locations may include high speed rural highways, high volume two-lane highways, or specific locations where there are distractions. If one pair of cantilever flashing lights would be visible to drivers in all approaching lanes, except the right lane which has a view of the post mounted signals, other flashing lights are not required on the cantilever arm. A pair of lights overhead for each approaching lane is not required, inasmuch as the warning aspect is at all times identical for all.

Breakaway or frangible bases shall not be used for cantilever signal supports. Where conditions warrant, escape area, attenuators, or properly designed guardrails should be provided.

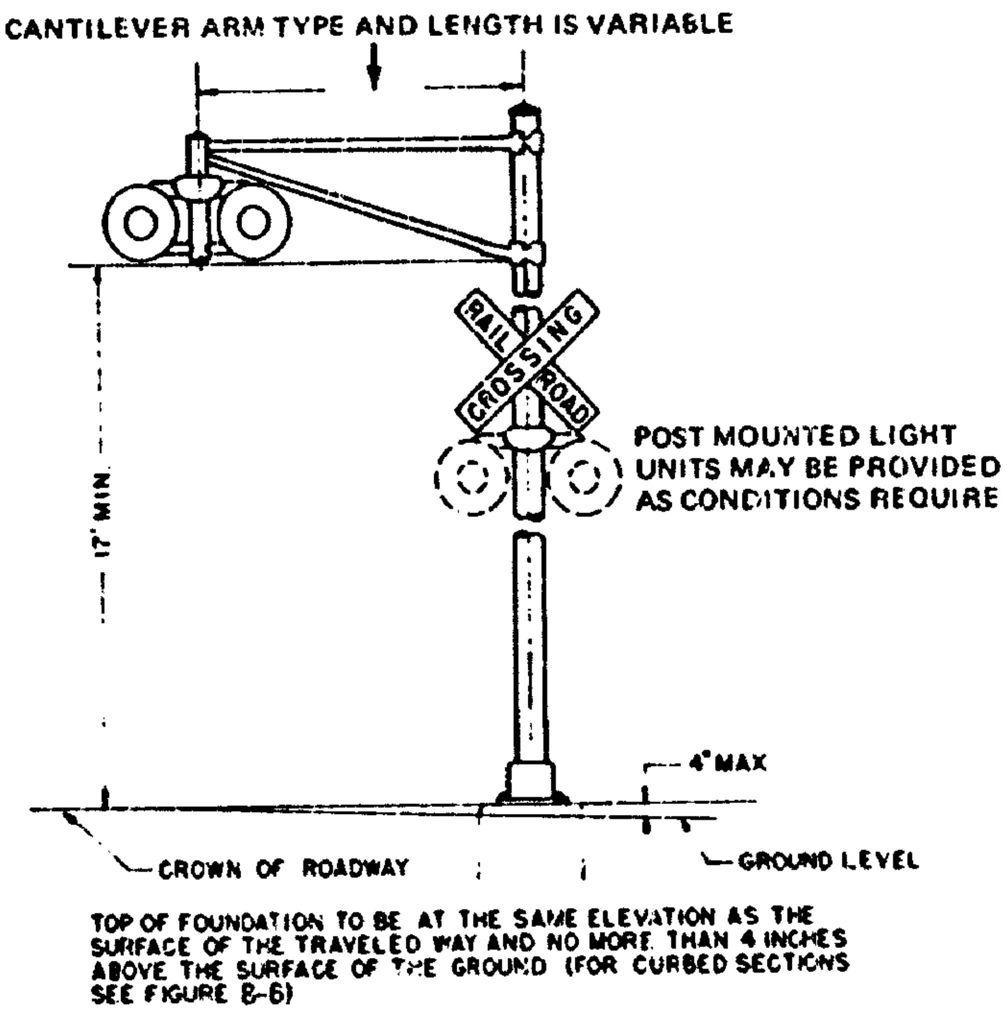



*Figure 8-4. Typical flashing light signal—cantilever supported.*

**8C-4 Automatic Gate**

An automatic gate is a traffic control device used as an adjunct to flashing lights. The device consists of a drive mechanism and a fully reflectorized red and white striped gate arm with lights, and which in the down position extends across the approaching lanes of highway traffic about 4 feet above the top of the pavement. The flashing light signal may be supported on the same post with the gate mechanism or separately mounted. A schematic view of the gate arm in the down position is shown in figure 8-5. This view does not show any of the several mechanisms used to raise and lower the arm.

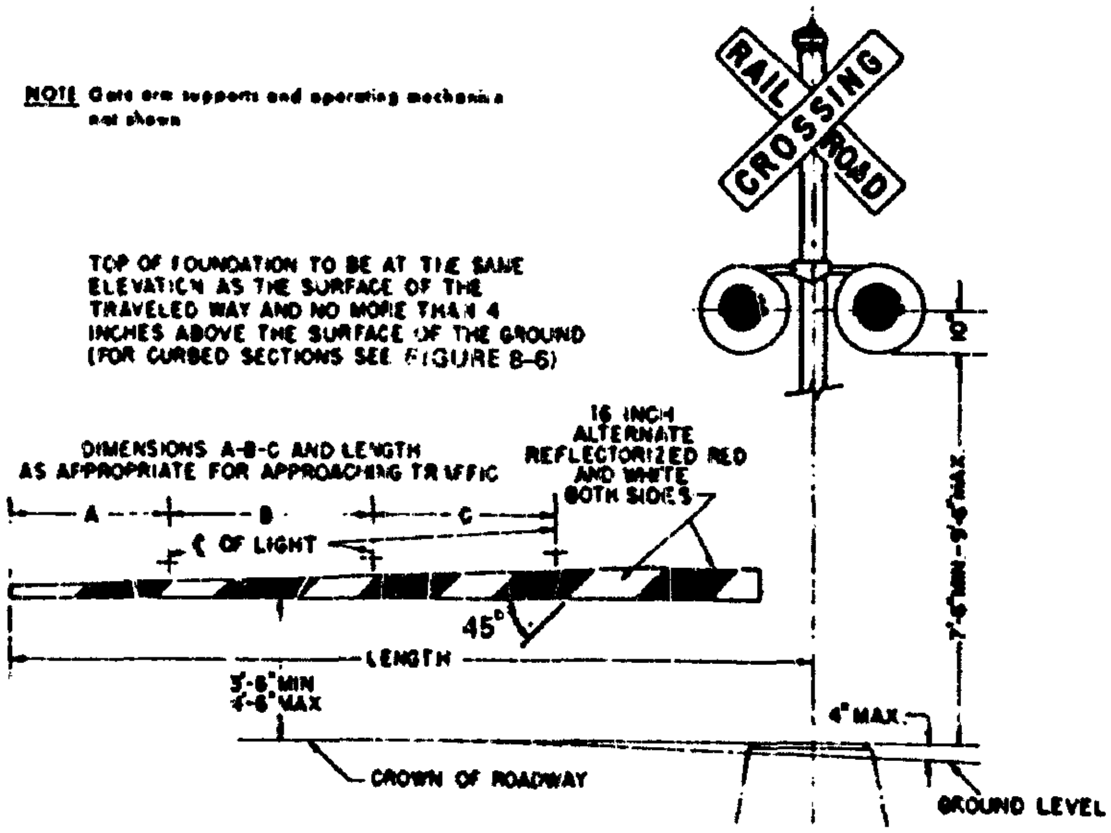



*Figure 8-5. Schematic view of automatic gate.*

# APPENDIX C

## REFLECTORIZATION OF RAILROAD ROLLING STOCK

Richard G. McGinnis, Department of Civil Engineering, Bucknell University, Lewisburg, Pennsylvania

This paper examines the effectiveness of retroreflectors on the sides of railroad rolling stock as a means of reducing highway-railroad grade-crossing accidents, and it estimates the benefits and costs of reflectorizing the U.S. fleet of railroad cars. Factors that affect the amount of reflected light received by a driver (including reflector characteristics, vehicle-reflector positioning, reflector cleanliness, headlight cleanliness and beam usage, windshield transmittance, and atmospheric conditions) were analyzed, and expected reflector illuminance levels were predicted. Under conditions expected in railroad operation, the analysis indicates that 15-cm (6-in) square delineators of high-intensity-grade reflective sheeting will permit detection distances sufficient for safe stopping in most highway situations, even under low-beam headlight illumination. Benefits were estimated from the 1975 Federal Railroad Administration accident data. Accidents were categorized into four groups based on the speeds of the train and motor vehicle and the collision point on the train. Reflector effectiveness for each of these groups was estimated by considering the type of crossing warning device, daylight accident rates, weather conditions, presence of obstructions, human factors associated with nighttime driving, and the train and motor vehicle speeds. The costs of a reflectorization program were estimated and a cost-effectiveness analysis was performed to assess the impact of visibility at grade crossings on annual benefits, since no reliable information is available on this important factor.

Conflicts between trains and automobiles at highway-railroad grade crossings have long been recognized as a major safety problem. Since the 1920s, the railroads and various local, state, and federal government agencies have worked to reduce hazards at the 220 000 public grade crossings in the United States.

Statistics indicate that efforts to improve the safety at grade crossings have been effective: in 1928 there were 2568 fatalities resulting from grade-crossing accidents (1); in 1977, this figure was 63 percent lower, even though vehicle kilometers of travel increased more than 800 percent during the same period (2).

Unfortunately, the problem of grade-crossing accidents has still not been completely solved. There were more than 12 000 grade-crossing accidents reported to the Federal Railroad Administration (FRA) in 1977. Consequently, FRA and the Federal Highway Administration are continuing their programs to reduce the hazards of railroad-highway grade crossings.

Most grade-crossing safety programs have been aimed at improving the warning devices at the grade crossing, but another approach is to improve the conspicuity of the train, so that motorists can actually detect it near a crossing. At some crossings, for example, street lights have been installed to improve nighttime visibility. On-train devices have also been proposed. Recently, interest has been high in the use of strobe lights on locomotives to improve both day and nighttime train visibility. Also, the use of reflectors on the sides of railroad cars has long been advanced by some as an effective way of increasing nighttime train visibility.

The purpose of this study was to examine the effectiveness of reflectors on the sides of railroad cars as a means of reducing grade-crossing accidents. The use of reflectors on railroad cars has been discussed in many documented studies (1,3-8), but the conclusions reached in these investigations are not consistent and indicate that the effectiveness of reflectors in reducing grade-crossing accidents may be either very considerable or absolutely minimal. This paper provides both an in-depth analysis of reflector effectiveness and an examination of the benefits and costs of reflectorizing the sides of the U.S. railroad car fleet.

### REFLECTORIZATION

Reflectorization has its greatest safety potential for accidents that occur at night and involve a motor vehicle striking the side of a train. In many of these accidents, the motorist is apparently unable to see the train in time to stop the vehicle safely. Reflectors on the side of a railcar will reflect light from a motor vehicle's headlights back toward the vehicle and, to the driver, such reflectors will appear as light sources or "bright spots" against a dark background.

The approach taken to analyze the effectiveness of reflectorization was to examine first the factors that affect the amount of reflected light that can be expected at various distances from a grade crossing and then to compare these light levels with visual detection standards to see whether detection (and perception) of a train's presence is likely.

The type of reflector that would be used on railroad cars is called a retroreflector or reflexreflector. Retroreflectors reflect incident light back toward the light source in a narrow beam. Retroreflective materials are used extensively for highway signs, pavement markings, and motor vehicle markings.

The amount of light received by an observer from a retroreflector is affected by six factors: the reflective intensity of the reflector, its size, the intensity of the original light source, atmospheric transmissivity, windshield transmittance, and its distance from the observer. The relationship between these factors and illuminance received by the observer is given by Equation 1:

$$E_o = (I_o A R t^{2d} W)/d^4 \qquad (1)$$

where

- $E_o$ = illuminance received by the observer (lx),
- $I_o$ = intensity of the light beam toward the reflector (cd),
- $A$ = area of the reflector ($m^2$),
- $R$ = reflective intensity of the reflector [(cd/lx)/$m^2$],
- $t$ = transmissivity of the atmosphere per meter,
- $W$ = windshield transmittance, and
- $d$ = distance between the observer and the reflector (m).

A FORTRAN computer program was written to compute reflector illuminance received by a driver for various reflector (train) locations. The program used headlamp luminous-intensity distributions and retroreflector properties to determine expected reflector brightness. Values were computed for reflector locations from 30 m (100 ft) to 244 m (800 ft) in front of the motor vehicle and from 122 m (400 ft) to the left to 122 m to the right of the projected path of the motor vehicle. In addition, the program allowed for variation in the size, efficiency, and placement height of reflectors; the conditions of headlights, windshields, and

Source: Transportation Research Record 737, Traffic Control Devices, Geometrics, Visibility, and Route Guidance, Transportation Research Board, National Academy of Sciences, Washington, D.C., 1979.

atmosphere; and the intersection angle between the train and the motor vehicle.

## Reflective Intensity

The reflective intensity of a reflector depends on the grade of reflective material and on the incidence and divergence angles. The incidence angle is the angle from the light source to a line normal to the reflective surface, and the divergence angle is the angle between the line of sight of the observer and the path of light from the source (Figure 1).

The divergence angle is a function of the distance between the driver's eyes and the light source and the distance between the reflector and the light source. Because the distance between the light source and the driver's eyes is a constant, the divergence angle decreases as the distance between the vehicle and the reflector increases (Figure 1). In the analysis, dimensions for a typical U.S. passenger vehicle were used (9) and produced divergence angles of 2° to 0.14°.

The overall efficiency of a retroreflector is maximized when the divergence and incidence angles are both zero. Furthermore, since both the divergence and incidence angles vary inversely with reflector-vehicle separation, reflector efficiency will increase with separation between train and motor vehicle.

Retroreflective sheeting material is currently available in two grades: engineering grade and high-intensity grade. Analyses in this study are based on the reflective qualities of high-intensity-grade reflective sheeting, since the threefold to fourfold increase in reflectivity that high-intensity grade provides over engineering grade is needed to produce illumination levels that are sufficiently bright at long distances for grade-crossing safety. The low range of divergence angles expected also contributed to the selection of high-intensity grade.

Reflector efficiency is defined as the proportion of the original reflectivity that a reflector maintains under given operating conditions. Reflector efficiency decreases with time because of deterioration of the reflective material and accumulation of dirt and grime. The average efficiency of the reflectors on a fleet of cars would depend on the frequency of reflector replacement, the level of reflector maintenance, the operating environments of the railcars, and the durability and dirt-resistant qualities of the reflective material.

Limited data are available on the decreased reflector efficiency that can be expected from continuous use of retroreflectors on railroad rolling stock. However, a leading manufacturer of reflective materials advertises that silver high-intensity reflective sheeting used on vertical surfaces for highway signs will have a reflective intensity of 200 (80 percent of original specified reflectivity) after 10 years of service and proper cleaning of the material, while the effective performance life is decreased to seven years in areas of abundant sunshine. In general, experience with high-intensity sheeting in highway use indicates an effective performance life of 12-14 years (10). Indications are, however, that the railroad environment is more severe than that experienced by highway signing and that a shorter life may consequently be expected for reflective sheeting used on railroad rolling stock. Nevertheless, the reflector efficiency question cannot be definitively answered before field tests of reflectors on railcars have been performed.

In the absence of reliable data, a reflector efficiency of 0.50 has been used in this study. Since the reflective intensities have been computed conservatively, the actual reflectivities used in the analysis represent approximately 30-40 percent of the reflective intensities of new silver high-intensity sheeting.

## Reflector Size

In the analysis, a reflector size of 0.023 $m^2$ (0.25 $ft^2$) was used since it is the largest size that can still be viewed as a "point source" under most conditions expected at grade crossings.

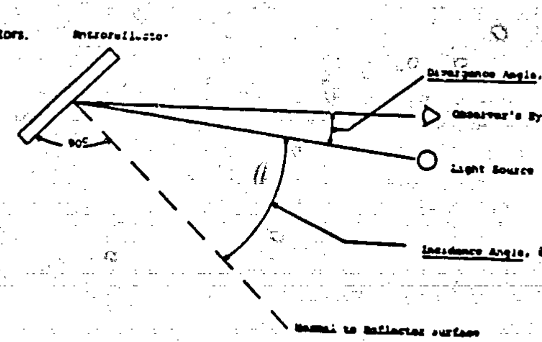
## Motor Vehicle Headlight Systems

The amount of light beamed on a reflector (and ultimately back to the driver) is a function of the location of the reflector in relation to the headlights, the type of headlight system, the mode of headlight operation (high beam or low beam), and the maintenance level of the headlights (alignment and cleanliness).

In most operational situations, the retroreflectors on the railcars will be located above the horizontal axis of the motor vehicle's headlight system. Under high-beam operation, a substantial amount of light is beamed upward; however, very little light is directed upward in the low-beam operational mode. But the amount of light incident on the reflector surface is enhanced at long distances due to the decreasing vertical angle between the reflectors and the headlight axis. For example, for a vertical separation of 0.3 m (1.0 ft) (see Figure 2) low-beam headlight intensity is 1500 cd at 30 m (100 ft) and 4500 cd at 244 m (800 ft).

The use of high-beam lights was studied by the Southwest Research Institute (11), which found that less than 25 percent of the 23 176 vehicles observed in an open road situation (high beams appropriate) actually used

Figure 1. Divergence and incidence angles of retroreflectors.



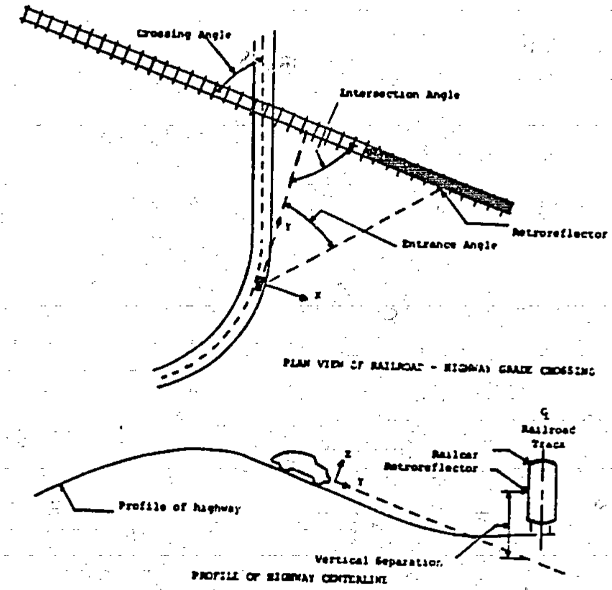



Figure 2. Visibility of retroreflectors at a typical railroad-highway grade crossing.

their high beams. Therefore, if reflectors are to be highly effective, they must be visible under low-beam illumination.

A headlight efficiency of 0.85 was used in all analyses. This figure is consistent with research findings (12, 13) for operation during dry-roadway conditions. During wet-road conditions, light reductions of 50 percent are not uncommon. However, recent research on the visibility of reflectorized overhead highway signs (14) indicates that sign illumination increases by a factor of more than two under wet-road conditions because of the increased amount of light reflected up from the wet pavement. Thus, the 0.85 headlight efficiency used in the analyses should be applicable to most driving conditions. Effects of improper aim of headlights were not included in the analyses because of inadequate data.

### Atmospheric Conditions

Atmospheric conditions affect the efficiency of any reflector. Fog and haze, for example, reduce all visibility, including that of light bounced off a retroreflector. In the analyses, a "light haze" condition [8-km (5-mile) daytime visibility] was used.

### Windshield Conditions

A windshield transmits only a portion of the total light incident on it. For untinted windshields, the transmittance is about 87.5 percent, but only about 72.5 percent of the light is transmitted through tinted windshields (15). Tinted windshields are known to decrease visibility distances at night; however, these decreases are usually less than 10 percent (16, 17). In the analysis, a windshield transmittance of 70 percent was used.

### Detection Level

Detection of reflected light depends primarily on its brightness and the contrast with its surroundings (3). The threshold illumination level for a point source viewed against a background luminance of 0.0034 cd/$m^2$ (0.001 foot lambert) (overcast, moon) is $24.7 \times 10^{-6}$ lx ($2.3 \times 10^{-6}$ footcandles) (18). This value represents the illumination level required for 98 percent probability of detection when the observer knows precisely where to look for the light, and it must be increased 5 to 10 times if the light is to be easily found. The Federal Aviation Administration's (FAA) detection level for pilots is 7.8 times this minimum threshold. If the light signal is to attract the attention of an observer who is not actively looking for it, then increases of 100 to 1000 times the threshold level are needed (19).

For the study, a three-region criterion was used to assess the detectability of various reflector illumination levels. It was assumed that the FAA detection level for pilots is the practical minimum illumination that can be expected to be detected by highway users in the vicinity of railroad-highway grade crossings. A driver familiar with the sight of railcar reflectors, approaching a grade crossing that he or she knows has high train volumes, should be able to detect a reflected light source at this level. Most drivers, however, would require an illumination level significantly higher than the FAA threshold for detection.

An illumination level of 1000 times the minimum threshold [$24.7 \times 10^{-3}$ lx ($2.3 \times 10^{-3}$ footcandles)] should be sufficient to make the reflector detectable to all but the few drivers who are completely oblivious to their driving environment. In the region between 100 and 1000 times the minimum threshold ($24.7 \times 10^{-4}$ lx to $24.7 \times 10^{-3}$ lx), the reflector "probably" would be detected. Between the FAA threshold and the 100-times level, the reflector could "possibly" be detected.

## RESULTS

Figure 3 shows the three ranges of reflector visibility

Figure 3. Visibility regions for an intersection angle of 90° for low beams and for high beams.

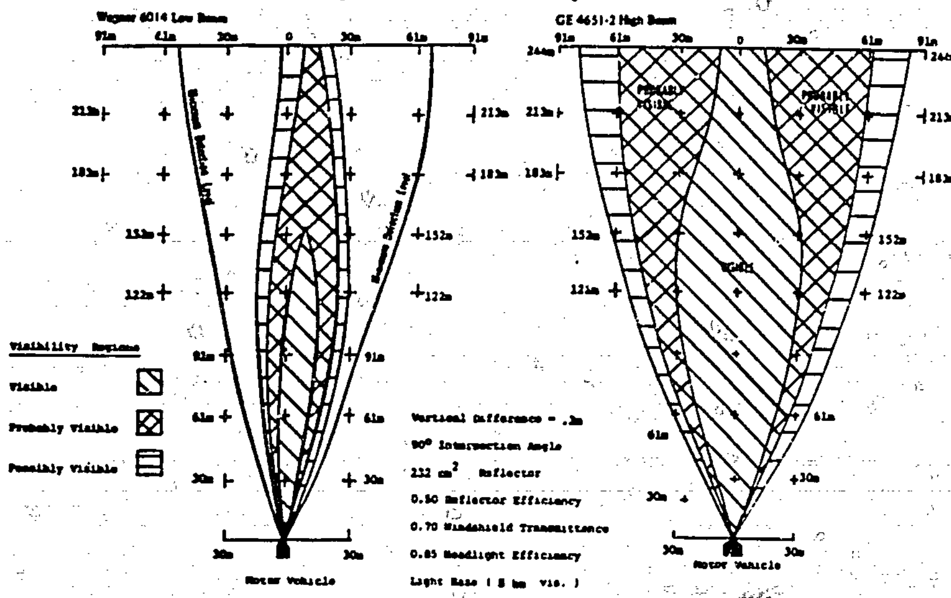
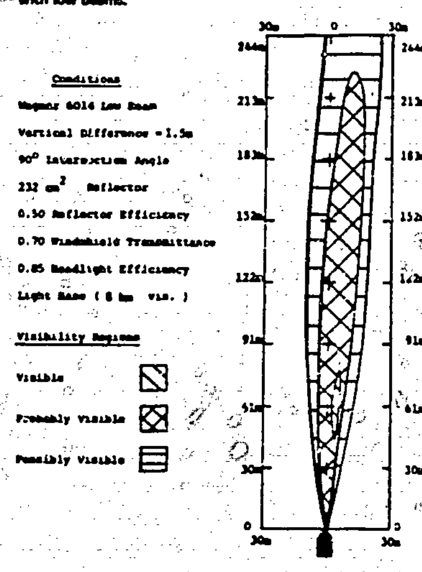



Figure 4. Visibility regions for a 1.5-m vertical difference with low beams.




expected from a two-lamp low-beam system and a four-lamp high-beam system. As expected, the "visible" region is much larger for high-beam illumination than it is for low-beam illumination. Even so, the "visible" region for the low beams extends 152 m (500 ft) from the vehicle and the "probably visible" region beyond 244 m (800 ft). For the crossings represented by these figures, there is little question that reflectors would be visible with high-beam illumination and would most likely also be visible with low-beam illumination. Separate analyses performed indicate that changing the intersection angle to 45° does little to affect the visibility of the reflector.

The effectiveness of the reflectors is greatly influenced by the position of the reflector on the railroad car. Figure 4 shows the visibility regions for a reflector located 1.5 m (5 ft) above the plane of headlights, and a comparison of Figure 4 with Figure 3 for low beams shows that the impact of raising the reflector 1.2 m (4.0 ft) is a reduction of the "visible" region to practically zero, although the "probably visible" region still extends beyond 229 m (750 ft). The impact of a high reflector on visibility is much less when illumination is by high beams.

## Reflector Effectiveness

The analytical evaluation of reflector effectiveness indicates that retroreflectors on the sides of railroad cars should be detectable at distances between 152 m (500 ft) and 305 m (1000 ft) if illuminated by low-beam lights and between 274 m (900 ft) and 610 m (2000 ft, if illuminated by high-beam lights. Before any conclusions may be drawn about the effectiveness of the reflectors in eliminating grade-crossing accidents, two questions must be answered: How much sight distance is needed for safe stopping, and how inadequate is the visibility of unreflectorized cars?

Stopping distance for speeds of 16 km/h (10 mph) to 113 km/h (70 mph) for dry, wet, and icy pavements were computed by using a 2.5-s perception and reaction time. A stopping distance of 152 m (500 ft) should be

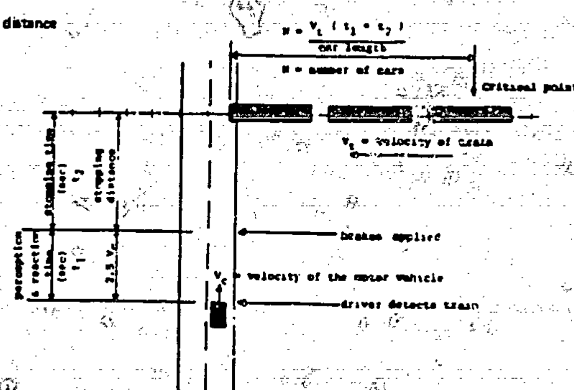
Table 1. Nighttime visibility distances for reflectorized and unreflectorized railroad cars.

| Type of Rail Car | Approximate Detection Distances* (m) | | | | | |
|---|---|---|---|---|---|---|
| | Two-Lamp Low-Beam System | | | Four-Lamp High-Beam System | | |
| | Possibly Visible | Probably Visible | Visible | Possibly Visible | Probably Visible | Visible |
| Empty flat car | | | | | | |
| Unreflectorized | | | | | | |
| Black | <30 | <30 | <30 | 91 | 46 | <30 |
| Red | 30 | <30 | <30 | 137 | 91 | <30 |
| White | 91 | 46 | <30 | 213 | 152 | 46 |
| Reflectorized | 366 | 305 | 152 | 610 | 457 | 274 |
| 15-m box car | | | | | | |
| Unreflectorized | | | | | | |
| Black | 30 | <30 | <30 | 183 | 137 | 46 |
| Red | 46 | 30 | <30 | 244 | 213 | 76 |
| White | 137 | 76 | 30 | 488 | 335 | 137 |
| Reflectorized | 366 | 305 | 152 | 610 | 457 | 274 |

Note: 1 m = 3.3 ft

*Based on data reported in the 1947 edition of the IES Lighting Handbook

Figure 5. Relationship between vehicle stopping distance and critical point on train.




adequate for most highway driving speeds and, since visibility distances of reflectors even when illuminated by low beams exceed 152 m, retroreflectors on the sides of railcars should provide adequate visibility to allow for safe stopping under most conditions experienced at railroad-highway grade crossings.

In order to assess the visibility of existing unreflectorized railcars, visibility ranges comparable to the three used for the reflectors were estimated for a standard 15-m (50-ft) boxcar and for an empty 15-m (50-ft) flatcar (Table 1).

Visibility ranges of unreflectorized railroad cars are significantly shorter when illumination is provided by low-beam headlights rather than by high beam. With the exception of dark-colored empty flatcars, visibility distances for unreflectorized cars illuminated by high-beam headlights seem to be adequate for safe operation at normal highway speeds. On the other hand, illumination by low-beam headlights does not even allow for safe stopping distance at 32 km/h (20 mph).

Given the low visibility of unreflectorized railcars illuminated by low-beam headlights and the fact that most drivers fail to use high-beam lights when they should, it follows that the increased visibility distances provided by reflectorization of railcars should be effective in eliminating certain grade-crossing accidents. The extent of the benefits anticipated from reflectorization is discussed next.

## Benefits of Reflectorization

Accidents were classified into four groups. Category 1 consisted of accidents in which the motor vehicle strikes the train at a point that is far enough back along the train to indicate that the driver could have stopped safely if he or she had detected the train's presence just as it started crossing the highway. To determine which accidents met this criterion, a "critical point" (see Figure 5) on the train was computed by using the motor vehicle speed, the train speed, and the condition of the pavement (dry, wet, or icy). If the motor vehicle hit at or behind the critical point, the accident was included in category 1 if the location hit was not the first car or unit and in category 2 if the location hit was the first car or unit. Accidents involving a motor vehicle hitting a train forward of the critical point were included in category 3. Category 4 comprised all accidents in which the train hit the motor vehicle.

Category 1 includes the accidents most likely to be eliminated by reflectorization. Assuming that reflectors are effective, then the only nighttime accidents in this category that would not be eliminated are those that occur at grade crossings where the view of the tracks is obscured, those that occur because of motor vehicle equipment failures, or those that occur because of human factors such as poor eyesight, intoxication, attempted suicide, sleeping at the wheel, or bad judgment.

that have active-warning systems (see Table 2). The base figure of 4823 potentially preventable accidents includes accidents in which the motor vehicle was struck by the train, i.e., category 4 accidents.

Without specific regulations to require the cleaning of reflectors, Hopkins' no-maintenance scenario is probably the most realistic. However, it certainly would be nice to have some research on the question of the impact of lack of reflector maintenance on reflector brightness.

Hopkins' suggestion for using a single cost estimate with estimates of minimum and maximum benefits to give a more realistic idea of the program's benefit/cost ratio is impossible until better cost data are available on installation costs and, more importantly, until information on grade-crossing visibility is obtained, so that ranges of benefits can be established. At this point, it is impossible to estimate minimum benefits.

## REFERENCE

26. R. G. McGinnis. The Benefits and Costs of a Program to Reflectorize the U.S. Fleet of Railroad Rolling Stock. Federal Railroad Administration, 1979.

*Publication of this paper sponsored by Committee on Railroad-Highway Grade Crossings.*

A smaller proportion of the accidents in category 2 is expected to be rectified by reflectorization. In order for an accident to be included in category 2, it must have had a critical point of less than 15 m (50 ft) (one car length). In some cases the short critical distances were caused by a blank in the data field for either the motor vehicle speed or the train speed.

Categories 3 and 4 contain those accidents least likely to be eliminated by reflectorization. In order for reflectors to be effective in preventing accidents from these categories, the train would have to be visible before it reached the grade crossing. Since the analytical studies of reflector effectiveness (Figure 3) do indicate that trains would be visible at up to 61 m (200 ft) before they reach the grade crossing, it is likely that some of the category 3 and 4 accidents could be prevented by reflectorization.

Calculation of Benefits

A three-step process was used to estimate the number of accidents that would be eliminated by reflectorization. First, the number of accidents that were potentially caused by nighttime visibility problems was estimated from the 1975 FRA computer-file accident data. Next, accidents occurring under circumstances in which reflectors would not be effective (e.g., bad weather, visual obstructions, intoxicated drivers) were eliminated. Finally, the accidents were reduced to reflect the proportion of grade crossings in which highway-railroad geometry does not allow for effective use of reflectors.

A comparison was made of the accident rates at night (and dawn or dusk) with those that occur during daylight. Relative accident rates for each of the four categories of accidents are given in the table below.

| Item | Category 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Passive warning | | | | |
| Dawn or dusk | 3.7 | 3.1 | 1.4 | 1.7 |
| Night | 9.2 | 4.0 | 0.9 | 1.4 |
| Active warning | | | | |
| Dawn or dusk | 3.2 | 2.6 | 1.5 | 2.1 |
| Night | 7.5 | 3.6 | 1.8 | 2.0 |
| All crossings | | | | |
| Dawn or dusk | 3.4 | 2.9 | 1.4 | 1.9 |
| Night | 8.6 | 3.9 | 1.2 | 1.6 |

The accident rates are expressed as ratios and indicate the relative occurrence rate of each accident category in relation to the daylight rate. For example, the value of 9.2 for category 1 accidents occurring at night at crossings that have passive controls indicates that this particular type of accident is 9.2 times more likely to occur at night than it is during daylight. Variations in train traffic volumes by time of day have not been considered in determining these relative accident rates. It is assumed that train volumes at night are equal to or less than daylight volumes and thus do not add to the decreased exposure rate that occurs at night.

Some accident reduction is expected at actively protected crossings. Previous studies of reflectorization have limited the benefits to passively protected crossings on the assumption that actively protected crossings already inform the motorist of the impending presence of a train and that reflectors would add nothing to warn the driver. A study of driver behavior at signalized railroad crossings (20) found a surprisingly high rate of "critical incidents" (vehicles not stopping for the signal or zigzagging around fully descended gates) during signal alarm periods. Furthermore, the fact that the nighttime category 1 accident rate at actively protected crossings is more than seven times the daytime rate indicates that visibility is most likely a contributing factor in these accidents. Since no program of reflectorization could hope to provide visibility levels better than those experienced in daylight conditions, the daylight accident rates were used as the upper limits on effectiveness of reflectorization.

The relative proportions of travel occurring during the day, dawn or dusk, and night periods were used to compute the number of accidents that corresponded to the daylight accident rate. For example, there is 32 percent as much travel at night as there is during daylight; thus, one would expect 32 percent as many accidents to occur at night as occur during the day if visibility and other nighttime-related phenomena are not a problem. The numbers of accidents potentially caused by nighttime visibility problems were obtained by subtracting 32 percent of the daylight accidents from the night accidents and 6.3 percent of the daylight accidents from the dawn or dusk accidents. These values are shown in Table 2.

It is assumed that the daylight accident rates include those accidents caused by motor vehicle equipment failure and human factors. It seems reasonable to assume that accidents resulting from motor vehicle equipment failures, attempted suicide, heart attacks, or bad judgment should be equally likely to occur at night as they are during the day. On the other hand, accidents resulting from human factors such as poor eyesight, intoxication, or sleeping at the wheel are more likely to occur at night than during the day.

Category 1 accidents represent 3.8 percent of all grade-crossing accidents during the day. Since this category of accidents is caused primarily by visibility problems that should not exist during the day, its occurrence rate should represent the nonpreventable accidents discussed above. Accident data from Pennsylvania (22) were available in a form that allowed comparison between grade-crossing accidents and general highway accidents. A total of 3.6 percent of the 274 grade-crossing accidents that occurred in Pennsylvania in 1976 were caused by motor vehicle equipment failure and human factors.

Reflectors are effective only when the driver is able to see them and perceive that the reflectors are on a train. Visibility of the reflectors can be affected by physical obstructions, weather conditions, and human factors such as poor eyesight and intoxication. The ability to perceive and react to the situation is affected by the drivers' attentiveness or degree of intoxication. It was estimated that 65 percent of all drivers were alert.

Table 2 shows the percentages of accidents that occurred under the various conditions that would permit reflectors to be effective. Data on the presence of obstructions and adverse weather (fog, snow, or ice conditions) were obtained from the FRA accident file.

Alcohol and Other Human Factors

Certain causal factors in accidents are more prevalent during the night than during the day. Accidents caused by excessive use of alcohol, drowsiness, and poor eyesight fall into this category.

Limited data are available on the roles of alcohol and other human factors in railroad-highway grade-crossing accidents. Data from Pennsylvania (22), Alameda and Sacramento Counties, California (23), and Dade County, Florida (24) were used in assessing the impact of these factors on reflector effectiveness. On the basis of the results of these studies, it is esti-

Table 2. Factors that affect the effectiveness of reflectors.

| Accident Type | Total Accidents | Caused by Daylight Factors | Caused by Nighttime Factors | Percentage With No Obstructions | Percentage Without Adverse Weather | Percentage With Acceptable Speeds | Reflector Effectiveness (%) |
|---|---|---|---|---|---|---|---|
| Passive warning | | | | | | | |
| Category 1 | | | | | | | |
| Night | 396 | 41 | 355 | 93.3 | 90.6 | 100.0 | 49.0 |
| Dawn or dusk | 31 | 8 | 23 | 96.4 | 75.0 | 100.0 | 35.5 |
| Category 2 | | | | | | | |
| Night | 375 | 83 | 261[a] | 90.1 | 94.9 | 100.0 | 38.7 |
| Dawn or dusk | 56 | 18 | 38 | 83.0 | 94.3 | 100.0 | 33.9 |
| Category 3 | | | | | | | |
| Night | 129 | 150 | 0[a] | 90.1 | 93.5 | 57.8 | 0.0 |
| Dawn or dusk | 41 | 30 | 11 | 79.5 | 87.1 | 57.8 | 7.1 |
| Category 4 | | | | | | | |
| Night | 1349 | 984 | 365 | 90.0[b] | 93.0[b] | 25.0 | 3.7 |
| Dawn or dusk | 336 | 194 | 142 | 90.0[b] | 93.0[b] | 25.0 | 5.1 |
| Total | 2713 | 1520 | 1193 | 89.0 | 92.2 | 50.3 | 16.1 |
| Active warning | | | | | | | |
| Category 1 | | | | | | | |
| Night | 255 | 34 | 221 | 95.6 | 94.7 | 100.0 | 51.0 |
| Dawn or dusk | 21 | 7 | 14 | 84.7 | 89.5 | 100.0 | 38.1 |
| Category 2 | | | | | | | |
| Night | 237 | 65 | 172 | 95.2 | 97.8 | 100.0 | 43.9 |
| Dawn or dusk | 33 | 13 | 20 | 87.5 | 96.9 | 100.0 | 33.3 |
| Category 3 | | | | | | | |
| Night | 145 | 82 | 63 | 90.6 | 88.5 | 57.8 | 20.3 |
| Dawn or dusk | 24 | 16 | 8 | 95.7 | 87.1 | 57.8 | 9.7 |
| Category 4 | | | | | | | |
| Night | 1157 | 571 | 586 | 90.0[b] | 93.0[b] | 25.0 | 6.7 |
| Dawn or dusk | 236 | 112 | 126 | 90.0[b] | 93.0[b] | 25.0 | 7.2 |
| Total | 2110 | 900 | 1210 | 91.4 | 93.4 | 46.5 | 17.9 |
| All crossings | 4823 | 2420 | 2403 | 90.0 | 92.7 | 48.6 | 16.9 |

[a]For category 3 accidents at passive warnings, the nighttime accident rate was less than the daylight rate. The anomaly is probably due to the misclassification of accidents into category 2 because of missing data for train or motor vehicle speed. 21 accidents were subtracted from the category 2 accidents to make up for the deficit in category 3 accidents.
[b]Estimated.
[c]From 1975 FRA Rail-Highway Grade-Crossing Accidents/Incidents Bulletin (21).

mated that 35 percent of the accidents involve drivers who are sufficiently impaired that they would not be expected to detect and perceive the presence of a train from illuminated reflectors.

Effects of Highway-Railroad Geometry

Very little information about the geometry (vertical and horizontal) of railroad-highway grade crossings is available. The Association of American Railroads (AAR)-FRA Grade-Crossing Inventory contains information about the crossing angle of the highway and railroad, but it contains nothing about the vertical or horizontal alignments of the two routes. The grade-crossing geometry, along with natural and manmade obstructions, determines the visiblity at a crossing.

The visibility requirements necessary to eliminate category 1 and category 2 accidents are different from those needed for category 3 and category 4 accidents. In category 1 and 2 accidents, it is only necessary to see the highway-railroad intersection. In order for category 3 and 4 accidents to be eliminated, it is necessary to see the train at some point before it reaches the crossing. The actual distance up the track that the train is required to be visible depends on the train speed and the motor vehicle speed.

The proportion of accidents in which the train speed and motor vehicle speed are both such that the train would be within the range of the motor vehicle's headlights soon enough for the driver to stop is shown in Table 2. For category 1 and 2 accidents, this value is 100 percent, since the train does not have to be seen until it is across the intersection.

The overall effectiveness of reflectorization (assuming adequate crossing geometry for proper visibility) was found by multiplying the percentages for "no obstructions," "without adverse weather," "alert drivers" (65 percent), and "acceptable speeds" by the proportion of total accidents that were caused by nighttime factors. These effectiveness values are shown in Table 2.

Table 3 summarizes the maximum benefits anticipated from reflectorization. These are the benefits that would accrue if all crossings had the proper geometry to allow for adequate nighttime visibility. The numbers of fatalities and injuries and the amounts of property damage were obtained from the FRA 1975 computer-file accident data. Property-damage figures include damage to the motor vehicle, the train equipment, and the track and signal structures.

Costs of Reflectorization

The costs of a reflectorization program were divided into five categories of costs: initial material costs, initial installation costs, annual replacement costs for reflectors destroyed by vandals or train operations, annual maintenance costs for cleaning reflectors, and program implementation costs. Costs are based on the following assumptions:

1. High-intensity, high-tack reflective sheeting is used at a cost of $23.14/m^2$ ($2.15/ft$^2$).
2. Each railroad car is equipped with four (two per side) 15x15-cm (6x6-in) squares of reflective sheeting.
3. Each locomotive is equipped with six (three per side) 15x15-cm squares of reflective sheeting.
4. Five percent wastage of material occurs.
5. The installation rate is 30-60 reflectors/work hour.
6. Labor costs are $20/h.
7. No special handling of cars is required for installation or maintenance (work will be done during required inspections).

Table 3. Maximum annual benefits of reflectorization.

| Accident Type | Total Accidents | Reflector Effectiveness (%) | Reduction in Accidents | Reduction in Fatalities | Reduction in Injuries | Reduction in Property Damage ($) |
|---|---|---|---|---|---|---|
| Passive warning | | | | | | |
| Category 1 | | | | | | |
| Night | 396 | 49.0 | 194 | 17 | 82 | 257 740 |
| Dawn or dusk | 31 | 35.5 | 11 | 0 | 3 | 5 000 |
| Category 2 | | | | | | |
| Night | 375 | 38.7 | 145 | 5 | 47 | 98 510 |
| Dawn or dusk | 56 | 33.9 | 19 | 0 | 7 | 11 100 |
| Category 3 | | | | | | |
| Night | 129 | 0.0 | 0 | 0 | 0 | 9 |
| Dawn or dusk | 41 | 7.1 | 3 | 0 | 1 | 2 900 |
| Category 4 | | | | | | |
| Night | 1349 | 3.7 | 50 | 3 | 13 | 48 124 |
| Dawn or dusk | 336 | 5.1 | 17 | 2 | 4 | 20 441 |
| Total | 2713 | 16.1 | 439 | 27 | 157 | 443 825 |
| Active warning | | | | | | |
| Category 1 | | | | | | |
| Night | 255 | 51.0 | 130 | 7 | 64 | 136 850 |
| Dawn or dusk | 21 | 38.1 | 8 | 0 | 1 | 10 800 |
| Category 2 | | | | | | |
| Night | 237 | 43.9 | 104 | 4 | 50 | 70 370 |
| Dawn or dusk | 3 | 33.3 | 11 | 0 | 6 | 6 490 |
| Category 3 | | | | | | |
| Night | 145 | 20.3 | 29 | 4 | 16 | 39 040 |
| Dawn or dusk | 24 | 8.7 | 2 | 0 | 0 | 2 180 |
| Category 4 | | | | | | |
| Night | 1157 | 6.7 | 77 | 5 | 31 | 77 770 |
| Dawn or dusk | 238 | 7.2 | 17 | 1 | 4 | 19 820 |
| Total | 2110 | 17.9 | 378 | 21 | 172 | 363 400 |
| All crossings | 4823 | 16.9 | 817 | 48 | 329 | 807 325 |

Table 4. Estimated costs of reflectorizing U.S. railroad rolling stock.

| Cost Category | Unit Cost ($) | Estimated Cost Ranges (1977 $): First Cost ($000 000s) | Estimated Cost Ranges (1977 $): Equivalent Annual Cost* ($000 000s) |
|---|---|---|---|
| Material | $23.14/m^2$ | 4.0 | 0.8 |
| Installation | 0.33-0.67/reflector | 2.3-4.6 | 0.5-0.9 |
| Annual replacement (5 percent/year) | 0.90-1.25/reflector | - | 0.3-0.4 |
| Maintenance | 0.25-0.50/reflector | | |
| Once a year | | - | 1.7-3.5 |
| Once in two years | | - | 0.9-1.7 |
| Program implementation | | | |
| Research and development | 100 000 | | |
| Program development | 100 000 | | |
| Public education | 100 000 | | |
| Administration (per year) | 125 000 | | 0.2 |
| Total | | 6.3-8.6 | 2.7-5.8 |

Note: $1\ m^2 = 10.7\ ft^2$.
*Discount rate = 10 percent.

8. The reflective material has a seven-year economic life.
9. The discount rate is 10 percent.

Table 4 contains a summary of the cost estimates for the reflectorization program. Ranges of costs are given for items that cannot be estimated exactly, due to insufficient documented data. Annual costs are expected to be between $2.7 and $5.8 million. The cost of maintenance is the area that has the highest degree of uncertainty. It is also a major component of the total project cost. Research is needed to answer the questions about the frequency of maintenance required and its associated cost.

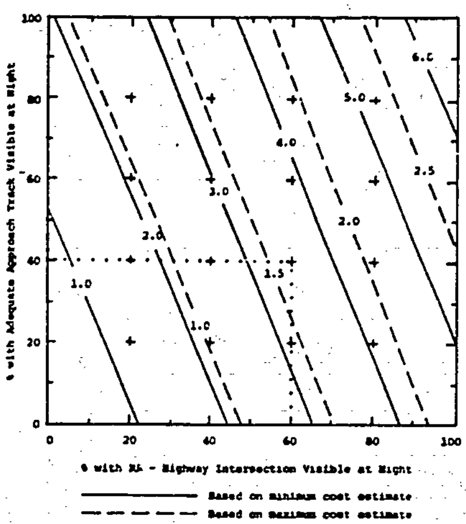
Another unknown that affects the cost of the project is the optimum pattern to be used in placing the reflectors on the railcars. Cost estimates in Table 4 assume that two reflectors are placed on each side of each car. It may be desirable to use additional reflectors on high freight cars to provide a delineating effect that will reduce driver perception time. Again, field research is needed to determine the best pattern to be used. Additional annual costs for extra delineators on high-side cars could run as high as $1.5-3.2 million.

## Cost-Effectiveness Analysis

The difficult task of assigning dollar values to the benefits that result from savings in human life and injury was accomplished by using values determined by the National Highway Traffic Safety Administration (NHTSA) (25). NHTSA has made a considerable effort to establish the societal costs of motor vehicle fatalities and injuries. If a reflectorization program is to receive funding, then its cost-effectiveness should be compared with the cost-effectiveness of other proposed safety programs to see whether it merits the spending of scarce dollars. Thus, the absolute values of the benefits assigned to injuries and fatalities is less important than the consistency of values used when comparing the cost-effectiveness of several competing projects.

A value of $318 000 has been used as the average societal cost of a fatality; this is the NHTSA 1975 value updated to 1977 dollars by using a 6 percent annual inflation rate. A value of $5000 has been used as the average societal cost of an injury. This value falls be-

Figure 6. Ranges of benefit/cost ratios for the reflectorization program.




tween the costs established by NHTSA for a moderate injury and that for a severe, but not life-threatening, injury. Property-damage values were obtained from the FRA Grade-Crossing Incident and Rail Equipment Accident files and were updated to 1977 dollars.

The anticipated annual benefits shown in Table 3 were converted into dollars by using the values given above. The actual level of benefits depends on the proportion of grade crossings that have suitable nighttime visibility.

Figure 6 shows the expected benefit/cost ratio for the reflectorization program (based on four reflectors per railcar) as a function of the proportion of grade crossings that have suitable geometry to allow for proper visibility. The solid lines represent the benefit/cost ratio that would result if the project costs were equal to the minimum cost estimate. The broken lines are based on the maximum cost estimate. For example, the dotted lines on Figure 6 show that, if 60 percent of the U.S. grade crossings have geometry such that the railroad-highway intersection is adequately visible and 40 percent of the grade crossings have geometry that allow for adequate visibility of a train as it approaches the intersection, then the expected benefit/cost ratio for a reflectorization program would be between 1.6 (maximum cost estimate) and 3.5 (minimum cost estimate).

Throughout the analysis an attempt has been made to estimate quantities conservatively. The effectiveness analyses were done by assuming low-beam headlight illumination. Much greater visibility is obtained by high-beam lights, and at least 25 percent of the drivers can be expected to use them.

It is important to note that the majority of the benefits are to society and not to the railroads. Other benefits to the railroads may result if liability costs are reduced by the decreased number of accidents. It is possible, however, that liability costs could actually increase if a federal regulation requiring reflectors were passed. With a regulation in force, a dirty or missing reflector could provide the avenue for a negligence suit against the railroad.

## FUTURE RESEARCH NEEDS

Research needs to be done to determine the size, pattern, and location of retroreflectors on the sides of railroad rolling stock that will optimize motorist detection and perception of a train's presence.

Research should be conducted to examine the decrease in reflectivity of retroreflectors that is caused by continuous use in railroad environments. This research is needed to determine whether maintenance is required.

Further research investigating driver behavior in the vicinity of railroad-highway grade crossings with both active and passive warning devices should be conducted.

## ACKNOWLEDGMENT

The research described in this paper was performed while I was employed by FRA as part of its Summer Professor's Program. Other individuals who contributed to this report are Christa Cudebec, Nancy Ulmer, and Helen Mathias, all of Bucknell University. I wish to express my appreciation to Bruce F. George, Edward S. Lord, and Richard E. Snow of FRA for their advice and assistance in this work. The contents of this paper reflect my views, and I am responsible for the facts and the accuracy of the data reported herein. The contents of this paper do not necessarily reflect the official views or policy of the U.S. Department of Transportation.

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## Discussion

Louis T. Cerny, Erie Western Railway Company, Huntington, Indiana

The reflectorization of railroad rolling stock appears to me to be a good idea. Certain factors would make it appear even more favorable than the study shows. In most cases the reflectors would be moving, causing increased probability of detection, and more than one reflector is likely to be in view at all times. I do not believe these additional favorable effects were taken into consideration.

Another favorable aspect is that the cleaning and application of the reflectors is a low-skill job and, because of the national nature of the car fleet, the work could be concentrated at railroad terminals in areas of high unemployment. This project would appear to involve direct federal funding because of the mobile nature of the railroad vehicles, which are not restricted to one state.

It appears, however, that a certain effect that weakens the case for reflectorization was not considered. In a substantial percentage of cases, headlights from highway traffic in the opposing direction can be seen through the spaces between the moving train cars, or under the bodies of the cars between the wheels, thus creating a very eye-catching effect that is more visible than the reflectors, and this is an additional circumstance under which the reflectors would not be effective.

In category 3 and 4 accidents, the locomotive's headlight would normally be visible long before the reflectors, because its visibility does not depend on reflectivity and because it is much higher off the ground than the reflectors. The illumination of objects around the crossing by the locomotive headlights as the train approaches may also attract more attention to the train than the reflectors would, especially since this effect precedes the arrival of the train.

I am skeptical that reflectors on the cars could create a significant increase in attracting a motorist's attention when the crossing is protected by gates (which normally have flashing lights on the gate in addition to those on the mast); I believe, therefore, that accidents occurring at gated crossings are very unlikely to be prevented by reflectors. In some cases, the gate may actually block the view of the reflector. Is there any reason that the distinction between gates and flashers and flashers alone was not made? Perhaps the accidents that occur at gated crossings should be taken as the limit of the effectiveness of reflectors, rather than daylight conditions.

Perhaps a further analysis of category 2 accidents should be made. The paper indicates that in "some cases" accidents fell into this category because of a "blank in the data field." Notes in Table 2 indicate that some adjustment was made, but no justification is given. It would appear that a similar adjustment would be needed in the "active warning" category.

More than four reflectors per car (two per side) would probably be needed on cars more than 18 m (60 ft) long. Common types of cars, such as piggyback, automobile racks, and automobile parts cars are about 26-27 m (85-90 ft) long. It would seem that the maximum distance between reflectors should be about 9 m (30 ft). I feel that answers to these questions, which reflect both positively and negatively on the project, are worth evaluating.

John B. Hopkins, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts

McGinnis has carried out a comprehensive and penetrating analysis that appears to achieve as definitive an answer as can reasonably be expected concerning the costs and benefits of railcar reflectorization. His paper brings out many of the uncertainties that are inherent to our basic lack of knowledge concerning accident causation, driver behavior, reflector degradation in the railroad environment, etc. In most cases I find his assumptions and estimates to be quite reasonable. It is my purpose in these brief comments to address only a few aspects in which I feel the ambiguities are so important as to warrant special attention. My aim is not to criticize, for I have no substantive complaints with the study. Rather, I wish to emphasize sources of uncertainty that I consider to be relevant to interpretation of the results, particularly with reference to formulation of policy in this area.

McGinnis has effectively placed an upper bound (the daylight accident rate) on the safety benefits that might be associated with reflectorization. The question then becomes one of estimating appropriate reductions from this value due to various limitations. One could quibble over matters of headlight aim, the assumption of low-beam operation, stopping distances, etc. However, these are minor points, and they tend to balance one another. More complex is the need to assess whether those accidents identified as relevant are truly caused by visibility problems of a type that could be mitigated by reflectors. My subjective view is that reflector effectiveness as shown in Table 2 is somewhat optimistic, or at least represents only a reasonable upper bound, particularly at crossings that have active-warning systems. For example, I find it quite unlikely that 51 percent of the drivers who fail to respond to conventional railroad-crossing flashing lights (some with gates) for night-related reasons will be deterred any more effectively by railcar reflectors. This is a relatively important question, since Table 3 shows that 46 percent of the expected accident reduction is to occur at such crossings.

A factor that affects both cost and effectiveness is reflector maintenance. One can envision many possible maintenance scenarios, each with its own benefit-cost implications. To my mind, the most realistic assumption is that of no maintenance at all. This substantially reduces estimated costs (by 33 percent for the "minimum cost" case and by 60 percent for "maximum cost"), while having a negative but indeterminate effect on safety. (It is appropriate to mention here that other types of reflectors could be used. For example, plastic devices used as highway delineators have somewhat less desirable optical characteristics in this application, but they appear to perform well in a rather dirty environment for many years without cleaning or replacement.)

In the context of policy formulation, another set of factors takes on real significance. These involve the effects of other activities that are expected to improve grade-crossing safety. For example, there are now under way major efforts to improve both passive- and active-warning systems and to achieve more widespread installation of train-activated devices. Reflectorized crossbucks, improved flashing lights, and increased use of gates are of obvious significance to the subject. Serious government and industry consideration is currently being given to widespread installation of locomotive-mounted strobe lights, which should do all that can be done through visibility enhancement to prevent the accidents McGinnis places in categories 3 and 4 (collisions occurring close to the front of the train). These represent 31 percent of the total estimated fatality reduction, which would thus be eliminated as a potential reflector benefit. There could also be a very significant impact on categories 1 and 2. (It is not claimed that strobe lights will necessarily prevent these accidents. However, for potential collisions near the locomotive, if strobes do not help, reflectors are unlikely to succeed either.)

The basic conclusions of the paper, as presented in Figure 6, assume maximum and minimum cost estimates. I suggest that for a more realistic estimate one should use a single no-maintenance cost assumption that still has two curves, based on minimum and maximum estimates of benefits. For the no-maintenance scenario, with full consideration of the limitations on potential safety effectiveness described above, reasonable minimum and maximum benefits might be approximately 25 and 75 percent of the values projected in the paper. The net effect of these modifications, which reduce both costs and benefits, is relatively small; I infer a subjective "most likely" benefit-cost ratio probably in excess of 1.0 but less than 2.0. It should be noted at this point that the benefits accrue primarily to society in general and only to a limited degree to the railroads. Installation at railroad expense would thus almost certainly have a benefit-cost ratio for them well below 1.0. From either the societal or railroad viewpoint, there may well be other investments in crossing safety that can be expected to yield greater benefits. To keep this matter in perspective, note that the above estimates imply a maximum saving of 12 to 36 lives/year, prior to correction for geometric factors that could easily diminish the benefits by another factor of 2 to 4. The net effect on crossing safety would thus be an improvement of approximately 1-2 percent. Thus, while reflectorization may ultimately prove to be a worthwhile step, with significant benefits, it does not appear to be of major importance to crossing safety in general.

I am in full agreement with the research needs McGinnis has identified, and I would only add reflector type and cost to the reflector optimization study. At the same time, the relatively limited promise of reflectorization, and the difficulty of obtaining definitive answers to these questions, seems to warrant only a modest priority for such research.

Otto F. Sonefeld, Atchison, Topeka, and Santa Fe Railway Company, Chicago, Illinois

As McGinnis indicated, the reflectorization of railroad rolling stock has been the subject of debate many times over the past few decades. Arguments favoring reflectorization have generally failed to show significant evidence of the effectiveness of this approach, particularly when compared with substantial argument in favor of other grade-crossing safety activities.

The McGinnis study is perhaps the most comprehensive look at this subject to date, although it leaves many questions unanswered. The problem, in my opinion, is in the attempt to draw fairly firm conclusions from data that do not lend themselves to such detailed analysis. McGinnis has done a commendable job under these circumstances, but it has required making certain assumptions that I feel should be more critically explored.

The part of the study that deals with reflector visibility distances appears to be well documented and reasonable. One of the shortcomings of previous proposals for reflectorization has been the inability of engineering-grade reflective material to function effectively in the severe railroad environment without diligent maintenance. The introduction of high-intensity reflective material would seem to diminish this problem, although it is not clear that even the use of that material would produce the 0.50 rate of efficiency used in the study. The recommended location for the reflective material is the most severe environment on a railcar.

This is not to say that diligent maintenance could not overcome this problem; however, experience in the automatic car identification (ACI) program does not indicate the capability or will of the rail industry to properly maintain the reflective material unless there is a return to the industry far greater than that provided by the ACI program. Such benefits are not apparent. In any event, the long-term effectiveness of the material seems open to question. Certainly, the cost-benefit ratios would be affected by increased maintenance requirements.

In the same vein, although the report acknowledges that a motorist may have a problem perceiving the recommended light source as a railroad train on a crossing, the perception time used in the report appears to assume that a motorist immediately recognizes the light source as a crossing hazard and comes to a prompt halt. I would suggest that a train crossing is unusual enough in the total traffic scheme that a longer perception time would be required to recognize it for what it is.

In developing the "critical point" used as the basis for analysis of the FRA accident reports, apparently vehicle speeds as stated on the reports are used. If so, it appears that vehicle speeds would tend to be consistently understated, inasmuch as the accident reports require speed at the time of impact, not the approach speed at which the decision to stop must be made. If I understand the rationale behind development of the critical point, this would then have the effect of placing that point further back in the train and thus of reducing both the number of accidents shown in categories 1 and 2 and the number of vehicles that would realize any benefits from reflectorization.

Highly important are the assumptions in this study that result in a finding that category 1 accidents at active-warning crossings are 7.5 times more likely to occur at night than during daylight. This further translates to a finding that reflectorization would prevent 51 percent, or 130, of these accidents. Raw data for 1975, however, show a total of 704 nighttime accidents at active-warning crossings of the ran-into-train variety, and 650 during daylight. The exact methodology for derivation of the figures in the study is not known, but my reaction is that the study figures are excessively high, compared with actual figures. This, of course, has a significant effect on the cost-benefit analysis in the report.

Also important to this analysis is the number of accidents used as the base figure, that is, potentially preventable. If 6:00 p.m. to 6:00 a.m. is a reasonable period in which to categorize nighttime accidents, the FRA report for 1975 shows only 1658 ran-into-train accidents in that period, many of which would involve striking the locomotive. The study, on the other hand, appears to be using a base figure of 4823 potentially preventable accidents. I do not understand these differences.

Another problem that is acknowledged but not used in the cost-benefit study is the number of crossings at which vertical and horizontal alignment is such as to eliminate these crossings as candidates for improvement by reflectorizing cars. I would suggest that the number is sizable.

Another category of accidents that is not discussed in the report, but that could possibly be eliminated from consideration for treatment by car reflectorization, is those ran-into-train accidents that occurred at illuminated crossings. This involves a minimum of 576 accidents in 1975 (677 in 1977), although the FRA report does not break these into nighttime and daylight accidents.

These comments are not meant to belittle the basic concept of reflectorizing rolling stock. Undoubtedly there are many crossing situations that lend themselves to this treatment. Whether they are of the magnitude suggested in the study is, in my opinion, a matter that requires more rigorous examination.

McGinnis correctly suggests further research into various aspects of this matter. I agree with these suggestions and, as indicated by my comments in this discussion, I would also suggest further refinements or clarifications of some of the critical factors involved in the development of costs and benefits associated with this subject.

## Author's Closure

It does not seem that blinking lights from opposing headlights shining through the spaces between moving railcars will affect the results of this study; if what Cerny says is true, and I think it is, then drivers aided by these blinking lights are already seeing the train and are safely stopping. Thus, they are not becoming FRA accident statistics and would not be touched by the potential benefits of reflectorization.

Cerny indicated a concern about the impact of locomotive headlights on potential reductions of category 3 and 4 accidents from reflectorization. There are problems in the use of locomotive headlights as a means of informing motorists about the impending danger of an approaching train. Locomotive headlights are placed close together, giving the impression of a single light, and are aimed in a very narrow beam. First, the lack of space between the two lamps does not allow a motorist to judge distance in the way he or she can with widely spaced automobile lamps. Second, the narrow beam of the locomotive headlight makes detection of these lights difficult for approaching vehicles. In a study conducted on the visual conspicuity of trains at grade crossings (8), Hopkins and Newfell concluded that a beam width of up to 150° would be required if visibility to a great majority of vehicles is to be achieved. Very little light is visible from a locomotive headlight at angles of greater than 15° to 20°; thus, locomotive headlights cannot be assumed to be effective in providing visibility to approaching vehicles.

The missing data responsible for the misclassification of certain category 3 accidents into category 2 do not seem to be too important in regard to the final study results. A sensitivity analysis was conducted to determine the impact of changing perception and reaction time on accident classification. This analysis indicated that the results are very insensitive to reaction and perception time, which also indicates that the results would be fairly insensitive to variations in vehicle and train speeds.

All three discussants expressed concern about the high effectiveness of reflectors shown at actively controlled crossings. I would point out that the analysis indicated that 51 percent of category 1 accidents would be eliminated at active crossings if all crossings had adequate visibility. I suspect that more of the accidents at active-warning crossings than at passive-warning crossings are caused by restricted visibility at grade crossings and would not be eliminated by reflectorization. However, this question cannot be answered until more is known about actual visibility at grade crossings.

Sonefeld questioned the source of several figures and the exact methodology used in determining them. A more detailed description of the methodology is available in an FRA publication (26). The 130 accidents referred to by Sonefeld represent 51 percent of the 255 category 1 accidents that occurred at night at crossings

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